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Evaluating Proposed Improvements of Public Rangelands

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RESEARCH SUMMARY

Concepts and processes for economic analysis of a rangeland development project are discussed. Various approaches to estimating the value of animal unit months of grazing use may be used. The actual method employed will depend on the analysis being performed and the availability of economic information. If the three major types of estimates are available the preferred value would be from production studies.

Ultimately, analysis results are to be used by forest supervisors, district managers, range managers, or others who must determine the use of and weight given to economic information. Such information may be a critical part of the decision or secondary consideration.

SB193

Evaluating Proposed Improvements of Public Rangelands

Fred J. Wagstaff

INTRODUCTION

Those who manage public rangelands are showing increased interest in formal economic evaluations of proposed improvement projects. First, Federal laws, such as the National Environmental Policy Act (1969), National Forest Management Act (1976), and Federal Land Policy and Management Act (1976) mandate such analyses as part of management planning. Second, the Office of Management and Budget (1972) requires formal evaluation and ranking of alternative proposals. Finally, severely limited budgets dictate that rangeland improvement projects be carefully evaluated, largely in terms of economic efficiency, and only those that are most efficient be funded. Although economics will not be the sole criterion for selecting projects, more weight is given this factor than in the past.

Both the U.S. Department of Agriculture, Forest Service and the U.S. Department of the Interior, Bureau of Land Management are developing specific guidelines for implementing the requirements broadly stated in the public laws (Federal Register 1981). The purpose of this report, therefore, is to outline a general procedure for conducting a comprehensive economic evaluation of proposed improvements and to review some basic principles of range economics.

OBJECTIVES AND CRITERIA

Economic analysis should be used to provide information to be tested against economic objectives or decision criteria; for example, a specific rate of return or level of net income. So doing, one could see whether proper amounts of relevant data were collected and included in the analysis, and if proper analytical procedures were used.

Specific requirements should be agreed upon by decisionmakers and analysts before analysis begins so that only relevant economic information will be generated. For example, if a decision criterion states that only those projects yielding a net annual return of over 8 percent will be considered for funding, the analyst should determine rates of return for each project. Too often objectives and decision criteria for both the planning and management of a rangeland area are anything but clearly understood. Broad goals may be easier to develop initially, but do not lead to systematically developed plans specific enough for quantitative analysis. Unclear decision criteria often lead to confusion for the analyst, the decisionmaker, and the public.

ECONOMIC ANALYSIS TECHNIQUES

When trying to determine economic effects of range projects through the application of proven techniques (Bartlett and Ralphs 1978; Young 1979), the analyst must generate accurate estimates of the economic value of range forage. Numerous evaluation techniques have been developed and tested over the past two decades (McCorkle 1959; Cook 1979; Young 1979). The choice of technique depends largely upon how the analysis is to be used and what economic information is needed. For example, an analysis of cash flow usually differs from a profit-loss analysis, and a benefit-cost analysis may differ from both. Agency budget and receipts accounting procedures yield different results than complete benefit-cost analysis.

The Bureau of Land Management and the Forest Service have recently strengthened economic analysis procedures (Federal Register 1981) to provide concise, logical, and consistent guidelines for treatment of costs for and benefits of range projects. The lack of complete accounting for costs and benefits causes problems when ranking proposed projects by comparing one to another because those left out may be important in one project and negligible in another. If projects are to be tested against a standard (such as fixed rate of return), it is very important to fully measure the total economic effects so that worthy projects can be included in agency programs.

BASIC CONCEPTS

Regardless of the technique used to estimate unit values of forage and other range outputs, it seems reasonable to expect all benefits and costs to be included. A simple model would follow the form $TNB = T_B - T_C$ where TNB = total net benefits, T_B = total benefits, and T_C = total costs.

In this general form there is no differentiation between private and public costs and benefits. A further breakdown of the general model would be $T_C = P_C + PVT_C$ where T_C = total project costs, P_C = public costs, and PVT_C = private costs.

The costs would include all costs directly attributable to producing and using the new forage. Benefits could, likewise, be looked at as a composite of the public and private sectors.

Rangeland managers need to consider all relevant costs and benefits. Public land managers can properly base decisions on a broader spectrum of costs and benefits than the private landowners, whose main criteria are net profits or cash flows from livestock sales. The values of watershed protection, wildlife, and other public values not fully measured in market terms have greater relevance to public managers as decision criteria.

To provide a basic comparison, the future situation for conditions "with" and "without" the proposal should be estimated. In other words, the costs and benefits for the expected life of the proposal should be estimated. For example, if the future held a substantial reduction in grazing without the development, and the development scenario maintained current livestock numbers, the difference would be the effect attributable to the project. Put in simple arithmetical form: Net Project AUMs = $W - WO$, where W = with project, WO = without project, and AUM = animal unit month.

This comparison of the project to doing nothing is only one comparison that needs to be made before one can be certain the project or design is the best. Best is defined as the project which would yield the largest level of net benefits (TNB or $T_B - T_C$).

In considering future benefits and costs, the problem involved with differing time frames must be taken into account. Many projects involve expenditures of funds for treatments and facilities at the beginning and do not show benefits for a period of years. This situation is commonly solved by use of a procedure called discounting where future values are reduced to show time preference. In short, future values are not given full par value with current values.

To make discounting possible an interest rate or discount rate reflecting the preference for current values over future ones must be selected. Public agencies use rates prescribed by the Water Resource Council or the Office of Management and Budget. Currently these rates are less than private money market rates. Analysts for the public agencies are not free to choose interest rates and are directed to apply the prescribed rate to all projects. This procedure leads to some degree of consistency so that project ranking can be accomplished.

Because a primary purpose of range development programs is to produce livestock forage, determining the value of forage is a critical element. There are numerous variations of three main methods for estimating forage value (Roberts and Wennergren 1963; Bartlett and Ralphs 1978). Studies using these methods could be grouped under the following categories: (1) comparisons with market-priced forages and feed sources, (2) capitalization of permit values, and (3) production analysis. Each of the methods makes different assumptions and has different data requirements. All approaches are theoretically compatible and should yield similar results if accurate data are available and the inherent assumptions are met.

Some authorities have argued for using grazing fees as the proxy for project benefits. This would be consistent with economic principles if the fee truly represented the net economic benefit or value of the forage to society. For public land grazing, the existence of the permit value substantiates the argument that Federal grazing fees do not generally represent the marginal value product of the forage (Gardner 1962; Roberts 1963; Martin and Jefferies 1965; Nielson and Roberts 1968). Using the fee as the net value of the forage would underestimate its value to the range user and the general economy (Andrus and Berglund 1977).

Where public rangeland projects are being analyzed, the most logical approach would appear to be counting all direct benefits and costs regardless of fee structures, which are based on noneconomic factors. This also needs to be done independently of agency budgeting and accounting guides, which preclude certain values (Byington and Child 1979). Not including some values for either the costs or benefits will result in biased conclusions.

Direct market comparisons are widely used to estimate unit values of goods where a market exists. Range forage is exchanged between individuals, so the primary criterion for a market is satisfied. Forage markets are largely local and informal, but one can usually determine the exchange prices for forage in a local area (Andrus and Berglund 1977). The values for rangeland use thus derived generally include items other than the forage, such as water, salt or minerals, herding, and fence maintenance. Those nonforage items need to be subtracted from the lease amount so that comparisons include only the forage. To be most accurate the ranges should be as similar as possible in terms of topography, forage, water, season of use, and location. The market comparison approach has the advantage of using current information about what actually transpires between range forage buyers and sellers. It rests on the concept that all units of a product should have an equal market price under competitive market conditions. Therefore, additional units of a given type of forage could be expected to have a value equal to those traded in the market.

Another economic principle of competitive markets is that substitutes should be of equal value. For example, high quality range forage and harvested roughage or irrigated pasture are technical substitutes for livestock production. There have been several attempts to place a value on range forage by comparing the values of substitutes. Various substitute feeds such as hay, concentrates, and field aftermath have been used in numerous studies (Roberts and Wennergren 1963). The problem with this approach is determining whether these actually are economic substitutes for range forage (Bartlett and Ralphs 1978). Is the substitute feed physically available and would it be technically possible to use it to substitute for range forage on a sustained basis? Feeding concentrates may make a good deal of sense during an unusually stormy period, but be entirely prohibitive as a standard procedure every year. Nevertheless, this approach can be used to give estimates of range forage values.

An almost limitless variety of ranch budgeting techniques have been used to estimate forage values (Roberts and Gee 1963; Nielson 1977; Gee 1981). Methods range from complex computerized models of entire operations to partial budgets using a few factors. Budgeting relies on accurate assignment of costs and returns to the factors of production. The major assumption of the budget method is the idea of obtaining a residual value where all factors other than one (forage in our case) have received their proper allocation of revenue. Any residual of revenue is then attributed to the forage and is used as an estimate of its value.

The budget approach can use actual data from rancher's records or synthetic data generated for a typical or model ranch or data from secondary sources. Each of the three methods would yield a similar value if perfect data were available and all assumptions met. In practice, there are differences and the choice of which value to use has not been consistent.

ESTIMATING PROJECT COSTS

Beginning with the cost side of the ledger, one would want to determine the cost for various project purposes. There would be investment costs for installation of the project, nonuse costs, maintenance costs, and yearly operational costs. These costs may be a mixture of public and private or all one or the other.

There is a question as to whether planning costs should be included as project costs. A reasonable approach seems to be inclusion of those design and layout costs incurred after a decision to proceed with project planning has been made and which would not be incurred if the project were dropped. General inventory and program level planning costs seem more appropriately to be part of the general overhead.

Initial investment must consider opportunity costs, which is the value of net returns foregone from the best alternative precluded by the project. For example, trees might be burned to increase forage production. If burned, the trees obviously cannot be used for fuelwood. If the rate of return from the increased forage produced by burning is less than the rate of return from fuelwood, net benefits would be increased by using trees for fuelwood. The concept of opportunity costs sets the lower boundary that project benefits must exceed to be feasible (Lloyd and Cook 1960). If the proposal does not yield a rate of return that exceeds that of an alternative use of the funds, the proposal should not be chosen from a purely economic efficiency viewpoint because superior economic returns are available elsewhere.

To use additional forage, additional expenditures for production items directly related to the project, such as herding, fence maintenance, salting winter feed, and medicine may be needed. Also, the level of capital investment and total operation costs may be increased if the scale of operation is changed (Nielson and Hinkley 1975). These costs are often overlooked in analysis of range projects, thus understating the total costs. To the rancher, these costs are very important because they affect ranch income and may also have an impact on the ranch's financial condition.

ESTIMATING PROJECT BENEFITS

Like costs, rangeland development benefits come in various forms, varying from increased forage to greater watershed stability. It seems logical to count all project benefits regardless of location or who receives them and irrespective of whether a user fee is charged.

Because all rangeland areas are also used for purposes other than livestock grazing, it is important to recognize these uses when formulating plans. Very often range development projects will be changed from the alternative that maximizes livestock use of forage to accommodate other uses.

Many rangeland goods or products are not traded in formal markets and are difficult to evaluate in economic terms. Economists have struggled with placing values on nonmarket items for decades and have not developed entirely suitable methods. Perhaps the best that can be done is to quantify these project effects in terms of species, numbers, cost per unit, or other terms. This would make comparisons among alternatives, including foregoing the project, meaningful enough to reveal physical and economic differences.

For purposes of developing a realistic model for economic analysis, all uses and outputs for a rangeland area need to be included. It is expected that some uses on some areas will be insignificant or small enough to preclude accurate measure. In such cases, the magnitude should be noted so a record of consideration and reasons for noninclusion is made.

SUGGESTED EVALUATION CHECKLIST

A. General
    1. Goals and specific management objectives for planning and management
    2. Economic decision criteria to be used in selecting proposed alternatives
B. Range livestock
    1. Class of livestock
    2. Season of use
    3. Integration of project forage into total livestock operation
    4. Value of forage (by one or more methods)
    5. Project costs (public and private)
        a. Development
        b. Maintenance
        c. Management
    6. Secondary economic impacts due to increased ranch income and project induced spending
C. Wildlife
    1. Kinds impacted by project
    2. Population changes due to project
    3. Uses of wildlife populations
        a. Consumptive
        b. Nonconsumptive
    4. Wildlife-related project costs
        a. Direct
        b. Associated
D. Watershed
    1. Water yield
    2. Time of release
    3. Quality changes
    4. Use made of water
    5. Unit values
        a. Benefits
    6. Watershed costs
        a. Direct
        b. Associated (costs associated with water use; treatment, conveyance, etc.)
E. Recreation
    1. Type of use
    2. Level of use
    3. Cost
        a. Direct
        b. Associated
F. Timber or fuelwood
    1. Type of product
    2. Unit value
    3. Change in quantity related to project
    4. Costs
        a. Direct
        b. Associated
G. Miscellaneous land uses
    1. Type of use
    2. Value of use

SUMMARY

The preceding discussion outlines concepts and processes for economic analysis of a rangeland development project. Various approaches to estimating the value of AUM's may be used. The actual method employed will depend on the analysis being performed and the availability of economic information. If all three types are available the preferred value would be those from production studies.

Ultimately, analysis results are to be used by forest supervisors, district managers, ranch managers, or others who must determine the use of and weight given to economic information. Such information may be a critical part of the decision or secondary consideration.

PUBLICATIONS CITED

Andrus, Cecil D.; Berglund, Bob. Study of fees for livestock grazing on federal lands. Washington, DC: U.S. Government Printing Office; 1977. 320 p. Stock No. 024-011-0087-9.

Bartlett, E. T.; Ralphs, M. Estimation of grazing values for the 1980 RPA Program. Fort Collins, CO: Colorado State University, Department of Range Science; 1978. 44 p.

Byington, E. K.; Child, R. D. Forage for domestic livestock on the National Forest System. Morrilton, AR: Winrock International Livestock Research and Training Center; 1979. 91 p.

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Cook, N. R. Multiple objective planning. In: Gum, Russell L.; Martin, William E., eds. Proceedings of multiple objectives workshop; 1979 February 27-March 1; Tucson, AZ. Agric. Misc. Rep. 7. Tucson, AZ: University of Arizona, College of Agriculture; 1979: 5-14.

Federal Register. Economic and social analysis: proposed policy. Washington, DC: U.S. Department of Agriculture, Forest Service; Federal Register 46(7): 22404-22414; 1981 April 17.

Gardner, R. D. Range restrictions and misallocation in grazing public range. J. Farm Econ. 44: 50-63; 1962.

Gee, C. K. Estimating economic impacts of adjustments in grazing on federal lands and estimating federal rangeland forage values. Tech. Bull. 143. Fort Collins, CO: Colorado State Experiment Station; 1981. 11 p.

Lloyd, R. D.; Cook, C. W. Seeding Utah ranges: an economic guide. Bull 423. Logan, UT: Utah State University, Agriculture Experiment Station; 1960. 19 p.

McCorkle, C. O., Jr., ed. Economic research in the use and development of range resources: Report 2, Western Agriculture Economics Research Council, Committee on the Economics of Range Use and Development in the West. Davis, CA: University of California; 1959. 159 p.

Martin, W. E.; Jefferies, G. L. Relating range prices and grazing permit values to ranch productivity. J. Farm Econ. 48(2): 233-242; 1966.

Nielson, D. B. Economics of range improvements: a ranchers handbook to decision-making. Bull. 466. Logan, UT: Utah State University, Agriculture Experiment Station; 1977. 52 p.

Nielson, D. B.; Hinkley, S. D. Economic and environmental impacts of sagebrush control on Utah's rangelands—a review and analysis. Res. Rep. 25. Logan, UT: Utah State University, Agriculture Experiment Station; 1975. 27 p.

Nielson, D. B.; Roberts, N. K. Position statement on current grazing fee issues and problems. Agric. Econ. Ser. 68-3. Logan, UT: Utah State University, Department of Agriculture Economics; 1968. 6 p.

Roberts, N. K. Economic foundations for grazing use fees on public lands. J. Farm Econ. 45(4): 721-731; 1963.

Roberts, N. K.; Gee, L. K. Cattle ranchers using public ranges: year-long-income adjustments to grazing fee and permit changes. Bull. 440. Logan, UT: Utah State University, Agriculture Experiment Station; 1963. 21 p.

Roberts, N. K.; Wennergren, E. B. The economics of selecting and administering state lands for grazing use. Bull. 443. Logan, UT: Utah State University, Agriculture Experiment Station; 1963. 36 p.

U.S. Laws, Statutes, etc. Public Law 91-190. [S. 1075], Jan. 1, 1970. National Environmental Policy Act of 1969. An act to establish a national policy for the environment, to provide for the establishment of a Council on Environmental Quality, and for other purposes. In its United States statutes at large. 1969. Vol. 83, p. 852-856. Washington, DC: U.S. Government Printing Office; 1970. [42 U.S.C. 4321, 433-4335; 4351-4357.]

U.S. Laws, Statutes, etc. Public Law 93-378. [S. 2296], Aug. 17, 1974. Forest and Rangeland Renewable Resources Planning Act of 1974. An act to provide for the Forest Service, Department of Agriculture, to protect, develop, and enhance the productivity and other values of certain of the Nation's lands and resources, and for other purposes. In its United States statutes at large. 1974. Vol. 88, pt. 1, p. 476-480. Washington, DC: U.S. Government Printing Office; 1976. [16 U.S.C. 1601].

U.S. Laws, Statutes, etc. Public Law 94-588. [S. 3091], Oct. 22, 1976. National Forest Management Act of 1976. In: United States code congressional and administrative news. 94th Congr. 2d sess., 1976. Vol. 2, p. 2949-2964. St. Paul, MN: Western Publishing Co.; 1976.

U.S. Laws, Statutes, etc. Public Law 94-579. [S. 507], Oct. 21, 1976. Federal Land Policy and Management Act of 1976 (FLPMA). An act to establish public land policy; to establish guidelines for its administration; to provide for the management, protection, development, and enhancement of the public lands; and for other purposes. In its United State statutes at large. 1976. Vol. 90, p. 2743-2794. Washington, DC: U.S. Government Printing Office; 1976. [43 U.S.C. 1701-1702, 1711-1781.]

U.S. Office of Management and Budget. Circular A-94. Washington, DC: U.S. Government Printing Office; 1972. 8 p.

Young, R. A. Economic values and trade-offs: the care of intermediate goods. In: Gum, Russell L.; Martin, William E., eds. Proceedings of multiple objectives workshop; 1979 February 27-March 1; Tucson, AZ. Agric. Misc. Rep. 7. Tucson, AZ: University of Arizona, College of Agriculture; 1979: 5-14.

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Basic economic concepts and analysis processes relevant to analysis of proposed range improvement projects are presented. These matters are of concern because increasing pressure for more consideration of the economics of public programs are being felt by land managers and administration. A checklist of factors to be considered in completing an analysis is included.

KEYWORDS: range economics, rangeland improvement economics, economic analysis

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Methods for Vegetation Sampling and Analysis on Revegetated Mined Lands

**Jeanne C. Chambers
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PREFACE

Revegetation is perhaps the most efficient and practical means of returning lands disturbed by surface mining to a productive capability. The challenge now, in the face of expanding energy concerns, is to assure that revegetation techniques adequately provide the site protection standards and other requirements imposed by society. Unfortunately, methods for assessing the success of revegetation are not well defined, nor are uniform standards available by which that success can be achieved. Normally, the relative success of revegetation is judged on the basis of a comparison of various attributes of vegetation with a reference area. However, complete standardization of methods of sampling vegetation is not available, and probably is not desirable, because no single method can satisfy all objectives.

This handbook is intended to provide an introduction to some of the major vegetation sampling methods that have been found useful for evaluating revegetation success. The characteristics of cover, production, density, and species diversity are the most useful for this purpose, and are discussed in some detail as they relate to revegetation of improved pastures, grazing lands, and woodlands. In addition, the problems and limitations of vegetation sampling are treated in terms of general vegetation types the sampler or inspector is likely to encounter. No pretext is made of providing an exhaustive treatment of the subject of vegetation sampling. However, selected references are included and should prove to be helpful in various circumstances. This handbook should be useful for both the seasoned professional and the novice field worker. It was originally prepared for the specific use of Region IV of the Office of Surface Mining, but has since been expanded and should be of use to all personnel interested in evaluating revegetation success on mined lands.

RESEARCH SUMMARY

This handbook outlines methods of sampling vegetation for the comparison of revegetated mined lands and reference areas as specified by Federal regulations implementing the Surface Mining Control and Reclamation Act of 1977. The various components of vegetation sampling are discussed in detail; however, only those methods proven to have a high degree of accuracy and precision are included. Selection of reference areas and sampling schemes are covered in addition to production, cover, and density sampling methodology. A viable method of comparing species diversity of revegetated and reference areas is presented. A statistical section outlines sample size determination and comparison of reference and revegetated areas using confidence limit estimates.

GUIDE FOR THE USE OF THIS HANDBOOK

I. Become acquainted with the laws and regulations.
   A. The Surface Mining Control and Reclamation Act of 1977 established the basic criteria for evaluating mined land revegetation efforts.
   B. The regulations implementing this criteria are found in the Federal Register Vol. 44, No. 50 – Tuesday, March 13, 1979.

II. Develop a scheme for classifying and mapping vegetation and for selecting reference areas and sample sites.
   A. The vegetation classification scheme selected must adhere to established terminology and methods.
      1. Range sites correlate soil and climax vegetation and are used to describe premine reference areas.
      2. Habitat types are based primarily on climax vegetation and secondarily on environmental characteristics and are used to describe premine and reference areas.
      3. Community types are determined according to current vegetation and also describe premine and reference areas.
      4. Response units are based upon similar topographic features, soil texture and depth, and vegetation, and are used to describe croplands, improved pastures, and reclaimed mining lands.
   B. Review the land use terms and the definitions presented by the OSM (Office of Surface Mining).
   C. Know the criteria for the selection of valid reference areas.
   D. Map the vegetation of the premine and reference area using the applicable classification scheme. Map revegetated areas as response units.
   E. Select sample sites that are homogeneous and representative of the area being sampled.

III. Understand the concepts of vegetation sampling.
   A. A random sampling scheme is necessary to obtain a valid estimate of the variance. Simple random sampling or systematic sampling with multiple random starts or random quadrat placement may be used.
   B. The quadrat size and shape will depend upon the type of vegetation being sampled.
   C. Sampling is timed to coincide with the maximum obtainable production value for current year's growth.

IV. Understand the production concepts and definitions used in this handbook. Production must be sampled on all revegetated and reference areas. The methods presented here are to be used unless production is to be compared to a standard. The methods used are then those used in establishing the standard.
   A. The harvest method is the most accurate method. It harvests total production from each quadrat and should be used during the year preceding bond release.
   B. The weight-estimate method requires both estimation and harvesting and may be used in all years except the one immediately preceding bond release.
   C. When grazing (utilization) has occurred before sampling, the amount of grazing (use) must be determined and production must be adjusted back to total production.
      1. The height-weight method for grasses allows estimation of use based upon the nonlinear relationship in grass plants of height to weight.
      2. The amount utilization on shrub plants is extremely difficult to estimate. Rough estimates may be obtained using the relationship of twig length or diameter to twig weight.

V. Become acquainted with cover sampling concepts. Cover must be determined on all revegetated reference areas using one or more of the following methods. If cover is to be compared to a standard, the methods used in determining the standard must be used.
   A. The point-quadrat method uses a point frame and is best suited to herbaceous vegetation below 3 ft (0.9 m) in height.
   B. The line-intercept method allows measurement of aerial cover of plants along a tape measure and is most accurate with grasses or shrubs with rounded canopies.
   C. The 35mm slide method involves photographing sample quadrats in the field and determining percent cover from the developed slide.
   D. Bitterlich's variable-radius method is used for sampling basal area and density of trees. Trees are tallied using an angle gage, optical wedge, or prism, and the probability of tallying any tree is proportional to its stem basal area.

VI. Assess density or stocking rate on revegetated areas that have been planted with shrubs or trees.
   A. Bitterlich's variable-radius method is used for sampling tree density, but is not well suited for small trees.
   B. The density-quadrat method for shrubs and trees requires a total count of all shrubs and trees within the quadrat and may be used on any size class.

VII. Understand the concepts of species diversity and know the important criteria for evaluating each sampling situation. Species diversity will be determined primarily only for wildlife habitat areas. The diversity of the revegetated area will usually be compared to that of a reference area using cover or production data collected according to the methods previously described.
   A. Shannon's Diversity Index provides independent measurements of species diversity for a revegetated area and its reference area based upon

both numbers of species and the evenness of the distribution of individuals among species. Its validity in the comparison of reference and revegetated areas is questionable, and it is recommended that it not be used.

B. Spearman's Rank Order Correlation Coefficient allows a direct comparison between a reference and a revegetated area of the apportionment of individual species or life forms. However, it can only be used under the constraints described in the text.

C. Modifications of Sorensen's Similarity Index and Spatz' Index yield a single comparison of both the numbers of species and the evenness of the distribution of individuals among species for a revegetated area and its reference area. They appear to be the most widely applicable measures of diversity for this sampling situation.

D. The choice of a similarity index must ultimately be based upon the objectives of the investigator.

E. Importance values reflect a species' overall contribution to a community (that is production or cover) and are used in the calculation of diversity indices and tests. Their selection is discussed in the text.

VIII. Know the statistical requirements stated in the regulations.

A. A two-stage sampling procedure will be used to insure that the required number of sample observations have been taken for each production, cover, and density sample.

B. A confidence-limit estimate must be calculated to determine if the revegetated area has 90 percent or more of the production or cover of the reference with the specified level of confidence.

C. The confidence-limit estimate will tell the investigator how many units (lb/acre or kg/ha) the revegetated area has exceeded or fallen below the requirements stated in the regulations.

D. The possibility of errors in data collection and analysis should be considered when the statistical tests show that the revegetated area has not achieved 90 percent or more of the production or cover of the reference area.

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Methods for Vegetation Sampling and Analysis on Revegetated Mined Lands

Jeanne C. Chambers
Ray W. Brown

INTRODUCTION: LAWS AND REGULATIONS

The Surface Mining Control and Reclamation Act of 1977, Public Law 95-87, established the basic criteria for evaluating successful mine revegetation. The act states that before a mining permit will be issued, a reclamation plan will be filed that includes a statement of:

> the productivity of the land prior to mining, including appropriate classification as prime farm lands, as well as the average yield of food, fiber, forage, or wood products from such lands obtained under high levels of management (Sec. 508.(a)(2)(c)).

The environmental protection performance standards of the act state that the affected land will be restored "to a condition capable of supporting the uses which it was capable of supporting prior to any mining, or to higher or better uses of which there is reasonable likelihood" (Sec. 515.(a)(2)). On all affected lands there will be established:

> a diverse, effective and permanent vegetative cover of the same seasonal variety native to the area of land to be affected and capable of self-regeneration and plant succession at least equal in extent of cover to the natural vegetation of the area, except that introduced species may be used in the revegetation process where desirable and necessary to achieve the approved post-mining land use plan. (Sec. 515. (b)(19)).

The act mandates the description of the vegetation community prior to mining and after reclamation in order to evaluate revegetation success. Specifically, the act and subsequent interpretations require the measurement and analysis of cover, production, and diversity. The specifications for assessing revegetation success are found in the Rules and Regulations published in the Federal Register Vol. 44, No. 50 - Tuesday, March 13, 1979. Appendix I of this handbook contains a complete copy of those sections pertaining to revegetation. Those sections pertinent to this handbook are as follows:

1. The ground cover and productivity of the revegetated area will be at least 90 percent of that of the reference area, with 90 percent statistical confidence or with 80 percent statistical confidence on shrublands.
2. If revegetation standards specified by a technical guide have been approved pursuant to 30 CFR 816.116 (b)(1), then ground cover and productivity must be at least 90 percent of those standards.
3. Vegetation cover on areas developed for fish and wildlife management or forest land will be at least 70 percent of that of the reference area, with 90 percent confidence.
4. Areas revegetated by trees or shrubs will have a minimum stocking of 450 trees or shrubs per acre (1 125/ha).
5. Permit areas 40 acres (16 ha) or less in size receiving 26 inches (66 cm) or more of annual precipitation will sustain an herbaceous vegetative ground cover of 70 percent for 5 full consecutive years and 400 woody plants per acre (988/ha) after 5 years. On steep slopes (greater than 20 percent), the minimum number of woody plants will be 600 per acre (1 500/ha).

Information on specific situations is in the Rules and Regulations (appendix I). Since the act states that the rules and regulations of individual States must equal or exceed those of the Federal Government, it will also be necessary to become familiar with the rules and regulations of the State of interest.

ELEMENTS OF DELINEATING REFERENCE AND REVEGETATED SAMPLE SITES

Vegetation Classification

A thorough understanding of vegetation type concepts is imperative for implementing good sampling techniques. The delineation of sampling units should be dependent upon the classification of vegetation types, and it is important that a classification be chosen that meets the specific sampling situation. The most frequently used classifications will be defined here, along with a discussion of when they should be used.

"Vegetation type" is a general term that refers, simply, to a plant community with distinguishable characteristics. In mapping vegetation or delineating sampling units, more refined concepts of vegetation communities are generally required. "Range site" and "habitat type" are two closely related terms that have widespread applicability for classifying vegetation communities. A range site, as defined in the Society for Range Management (SRM) Glossary of Terms (1974), is "a distinctive kind of rangeland, which in the absence of abnormal disturbance and physical site deterioration, has the potential to support a native plant community typified by an association of species different from that of other sites. This differentiation is based upon significant differences in kind or proportion of species or total productivity." The U.S. Department of Agriculture's Soil Conservation Service (SCS) and other agencies (such as the Department of the Interior's Bureau of Land Management, State agencies, universities) have determined the major range sites for those States having large areas of rangeland. The information is available in the form of "range site descriptions" that give the major soil type, precipitation zone, and potential vegetation of the site, as well as a range in species composition at potential and a range in production. The range site concept is useful even in those areas that do not have range site descriptions available; a complete explanation of their use can be found in section 302 of the SCS National Range Handbook (1976). In addition, a classical discussion of range site concepts is available in Dyksterhuis (1949). (A complete listing of the SCS State offices for OSM Region IV is provided in appendix II.)

Steele and others (1979) have presented this version of the classic Daubenmire definition of a habitat type:

> A habitat type is all the land capable of producing similar plant communities at climax. The climax plant community, since it is the end result of plant succession, reflects the most meaningful integration of the environmental factors affecting vegetation. Each habitat type represents a relatively narrow segment of environmental variation that is delineated by a certain potential for vegetative development. Although one habitat type may support a variety of disturbance-induced or seral plant communities, the ultimate product of vegetative succession anywhere within one habitat type will be similar climax communities. Thus, the habitat type system is a method of site classification that uses the plant community as an integrated indicator of environmental factors. These factors affect species reproduction, competition, and plant community development.
>
> The climax community type, or association, provides a logical name for the habitat type, for example *Pseudotsuga menziesii/Calamagrostis rubescens*. The first part of this name is based on the climax tree species, usually the most shade tolerant tree species adapted to the site. This level of stratification is called the series and encompasses all habitat types having the same dominant or characteristic undergrowth species in the climax community.

The concepts of range sites and habitat types are very closely related. Historically, range site concepts have been most often used to describe rangeland and grazing land, while habitat types have been used to classify forests and woodland. Range site classification has placed a greater emphasis, perhaps, on correlating soil and vegetation characteristics, while habitat type classification has dealt primarily with those characteristics inherent in the vegetation association, and secondarily with environmental characteristics. Both methods are valuable for the classification and mapping of vegetation.

Both range sites and habitat types describe vegetation communities in terms of their capability to produce a climax or potential vegetation community. They should be used to describe premining areas and natural reference areas that fit into the categories of woodland, grazing land, or rangeland. (Definitions for these categories are given later in this section.)

"Community type" is a term used to describe a vegetation community on the basis of its current vegetation. A community type has certain diagnostic climatic and edaphic features, but the successional status and climax vegetation of a community type are unknown. This term has the same uses as a range site or habitat type.

A delineation that describes most reclaimed mining areas is the "response unit." The climax vegetation of a response unit is unknown. A response unit is an area of land with similar topographic features, soil texture and depth, and vegetation. Response units can be compared by their capability to produce similar amounts and kinds of agricultural crops and pasture plants and to respond in a similar manner to various management techniques. Croplands and improved pastures, as well as revegetated mining land, can be accurately described as response units.

Land Use Terms

For the purposes of this handbook, it is necessary to clarify some definitions. These definitions are presented in the permanent regulatory program for surface coal mining and reclamation operations.

"Cropland" means land used for the production of adapted crops for harvest, alone or in a rotation with grasses and legumes, and includes row crops, small grain crops, hay crops, nursery crops, and orchard crops. Land used for facilities in support of cropland farming operations and which is adjacent to or an integral part of these operations is also included.

"Improved pastureland or land occasionally cut for hay" is land used primarily for the long-term production of adapted domesticated forage plants to be grazed by livestock or occasionally cut and cured for livestock feed. Land used for facilities in support of such use and which is adjacent to or an integral part of these operations is also included.

"Grazing land" includes both grasslands and forest lands where the indigenous vegetation is actively managed for grazing, browsing, or occasional hay production. Land used for facilities in support of ranching operations and which are adjacent to or an integral part of these operations is also included.

"Rangeland" means land on which the natural potential (climax) plant cover is principally native grasses, forbs, and shrubs valuable for forage. This land includes natural grasslands and savannas, such as prairies, and juniper savannas, such as brushlands. Except for brush control, management is primarily achieved by regulating the intensity of grazing and season of use.

"Woodland" refers to an open stand of deciduous or coniferous vegetation where woody vegetation covers approximately 25 to 60 percent of the ground area.

In addition to the "Range Site Descriptions," the SCS has developed for various states "Woodland Suitability Interpretations," which evaluate productive and management problems for woodland soil series and list the trees common to each soil series. "Pasture Suitability Groupings" are also available for certain states and list the best adapted pasture species for each soil series. "Woodland Suitability Interpretations," "Pasture Suitability Groupings," and "Range Site Descriptions" can all be of value to the investigator in classifying vegetation types into range sites, habitat types, or community types. They describe (1) the soils that a particular vegetation community occurs on, and (2) the major plant species that comprise the community (both climax native species and adapted introduced species in the case of Woodland and Pasture Suitability Groupings).

Because the vegetation community is a partial reflection of the soils that underlie it, soils can play an important part in classifying and describing vegetation communities. Although a vegetation community may occur on several soil series, each soil series is characterized by only one vegetation community. Therefore, a knowledge of the soil series in an area and of their potential natural vegetation can be a tremendous aid in mapping vegetation. Many counties in the United States have published soil surveys that completely map the soil series in the county and give management and cultivation interpretations for each series. These are available from the SCS. In addition, a soil series map is generally required before a mining permit is issued.

Reference Area Selection

Reference areas serve as standards of comparison to assess whether mined land areas have been successfully revegetated. Reference areas are land units maintained under appropriate management for the purpose of measuring vegetation ground cover, productivity, and plant species diversity that are produced naturally or by crop production methods approved by the regulatory authority. Reference areas must be representative of geology, soil, slope, and vegetation in the permit area.

The selection of reference areas will be dependent upon (1) the proposed land use for the revegetated area (wildlife habitat, improved pasture, cropland, and so forth) and (2) the approved revegetation plan for each individual mine. It is recognized that in many cases postmining vegetation and land uses may differ from premining vegetation and land uses. In Region IV of the OSM, an example of this would be the conversion of an oak savanna grazing land to an improved pasture of fescue or bermuda grass. In this case, the reference area would be an improved pasture of fescue or bermuda grass.

Mined and revegetated areas may differ significantly from the communities that originally occupied the site. Perhaps the most important of these, from a biological standpoint, is that the properties of the soil are often altered. The topography of the site may be changed and the composition of the vegetation may or may not be similar to that of the original site. Therefore, when comparing a revegetated area to a reference area, it will be necessary to integrate the factors that characterize the "new site" created through revegetation with those of the preexisting, established reference area. A list of the essential criteria for comparing revegetated and reference areas follows:

1. Individual site factors including elevation, precipitation, slope, and aspect must be the same for both areas.
2. Both areas will be comprised of the same plant life-forms and seasonal varieties of vegetation.
3. Management of the reference area will have to be consistent during the revegetation phase and the same as that proposed for the revegetation area. The condition class of the reference area (when dealing with rangeland) should be the same as that desired in the management plan for the revegetated area and should have a stable trend.
4. Although it is unlikely that the revegetated area will have the same soils as the reference area, it is important that certain edaphic characteristics be similar.
5. The reference area will have to be realistically comparable to the revegetated area, having the capability to produce a similar kind and amount of vegetation.

It is not essential that the reference area be immediately adjacent to the revegetated area as long as the above criteria are met. The two areas must not be separated by too great a distance, however, as differences in rainfall distribution patterns and other environmental factors could result in statistically different production, cover, and diversity values.

Reference areas for croplands should be a minimum of 1 acre (0.4 ha) in size. Larger areas of 2 to 5 acres (0.8 to 2 ha) are preferable, however, as they allow for variations in productivity due to differences in nutrient availability, topography, drainage, and so forth.

When the postmining land use of an area is grazing, special measures will have to be taken to ensure that past grazing has no effect on the accuracy of production, cover, and diversity sampling on either the revegetated area or the reference area. This can be accomplished in one of three ways:

1. Exclosures could be built on both the revegetated area and the reference areas to exclude livestock grazing during the years in which sampling is to occur. Exclosures should be a minimum of 1 acre (0.4 ha) in size on improved pastures and from 2 to 5 acres (0.8 to 2 ha) on grazing land and rangeland.
2. Grazing could be deferred or delayed on both the revegetated and reference areas until after sampling has been completed. The deferment applies only to those years during which sampling is scheduled. The proposed grazing management scheme should be adhered to during all other years.
3. Utilization correction factors could be used to adjust production figures if sampling occurs after livestock grazing, and cover values could be determined from basal instead of aerial values. These methods are detailed in production and utilization sections of this handbook.

Special consideration is required in the selection of reference areas for mined lands that are to be revegetated as wildlife habitat areas or that are to approximate the potential natural vegetation (woodland, rangeland, or grazing land). Areas must be chosen that are consistent with the management goals or the planned future use of the area. They must also be representative of the potential natural community as described by range site or habitat type concepts. Where differences in species composition exist between the potential natural community and the revegetated area, life-form and seasonality must be similar.

Vegetation Mapping

The actual classification and mapping of vegetation is best performed on the ground with the aid of aerial photographs. The criteria used for mapping vegetation units on both revegetated and reference areas include all of the elements previously discussed under vegetation types: soils, vegetation, and topography. The initial classification is done on the basis of similarities in plant species, the amount of vegetation produced, and the relative proportions of the individual species. SCS "Range Site Descriptions" and "Woodland Suitability Groupings" are helpful in distinguishing the differences between various range sites and habitat types.

Soil survey maps can be used to refine the boundaries between vegetation units. Although soil lines often coincide with vegetation unit boundaries, they should not be the sole basis for mapping vegetation. Individual characteristics of the vegetation community, such as production and species composition, must also be considered. In addition, there may be transition zones between the vegetation units that the plant scientist wishes to interpret differently than does the soil scientist.

The topographic features of aspect and slope are also important considerations because of their potential influence on vegetation communities. South and west slopes should generally be mapped separately from north and east slopes.

Aerial photos on the scale of approximately 1:20,000 (3.16 inches/mile or 8.03 cm/km) are normally the most convenient for this type of work. However, the scale will be determined by the intensity of mapping that is desired. A table of scales and equivalents for maps and photographs is provided in appendix III. Sheets of mylar (a clear plastic film) can be used to overlay individual photos for the mapping of soils and vegetation. A summary of all cartographic-related information sources compiled by the National Cartographic Information Center (NCIC) is in appendix IV. Bureau of Land Management Technical Note 287, "The Use of Aerial Photographs" and Eugene Avery's text, "Interpretation of Aerial Photographs," may prove useful to the reader.

Another essential tool for vegetation and soil mapping is the topographic map. An index to topographic maps of individual States as well as standard quadrangle maps published in the 7.5- or 15-minute series can be obtained from the Branch of Distribution, U.S. Geological Survey, 1200 South Eads Street, Arlington, VA 22202. In addition, a bibliography on "Selected Books on Maps and Mapping" by the USGS is included in appendix V.

Sample Site Selection

The selection of a sample site is made after the vegetation classification has been decided, mapping has taken place, and a reference area has been chosen. The sample site must be a homogeneous area that accurately represents the range site, habitat type, community type, or response unit being selected. The sample must be taken in a pure vegetation type and not in transition zones between adjacent types. The sample site should be located so it avoids the effects of neighboring vegetation types, roads, stream courses, and so forth.

The area selected as a sampling site must be large enough to obtain an adequate sample. A minimum sample unit of 2 to 5 acres (0.8 to 2 ha) is recommended for sampling reference areas; however, a larger area may be desirable for sampling rangeland and woodland. When evaluating revegetated areas, the entire area must be sampled. It may be desirable to stratify the area on the basis of major topographic features, soil conditions, or other major site conditions that may have a significant effect on vegetation characteristics.

CONCEPTS OF VEGETATION SAMPLING

Vegetation sampling is a means by which an investigator can make inferences about a plant community based on information obtained from intensive examinations of a small proportion or sample of that community. A true characteristic of the plant community is a parameter such as cover, production, or diversity, while an inferred characteristic is a statistic of that parameter. In vegetation sampling, we are concerned with inferring the true characteristics based on parameter statistics that are felt to represent the plant community. The importance of developing a sampling scheme that closely approximates the actual parameters of a community cannot be overemphasized, especially when dealing with small confidence intervals. It is critical that the sampling methods used be both precise (or repeatable) and accurate (or capable of delineating the true characteristics of the community).

It is very important that the sample provide an unbiased estimate of the variance and the mean of the parameters being studied. There has been a considerable amount of discussion in the sampling literature concerning the relative merits of random and systematic sampling. A simple random sample gives each individual in the population an equal chance of being selected that is independent of the chance of any other individual being selected. The estimate of the variance and the mean of the population is unbiased and consistent, and provides a valid basis for computing the estimate of its sampling error. A simple random sampling scheme may be, however, somewhat time-consuming to devise and execute in the field.

A systematic sample usually has one or more random starts and consists of a number of mechanically spaced sample plots along one or more transects. A systematic sample provides an unbiased and consistent estimate of the population mean and is often more time and cost efficient than a simple random sample. Systematic schemes are relatively easy to draw and to execute in the field. However, unless more than one random start is used, they do not provide enough information for computing an exact sampling variance. To insure obtaining an unbiased estimate of the population mean and a valid basis for computing the estimate of its sampling error, the methods presented in this handbook incorporate simple random sampling or systematic sampling with multiple random starts or random quadrat placement.

Cook and Bonham (1977) state that the "selection of a sample will depend upon: (a) the features of the population, (b) the variation among individuals, (c) the inferences to be made concerning the population, and (d) labor and time involved in collecting data." Each of these factors deserves critical consideration when choosing the proper sampling method. The concepts and methods explained in this handbook were chosen for their accuracy and precision. No attempt is made to review all of the various sampling methodology available, although the inherent weaknesses in certain techniques and the logic in choosing one technique over another is discussed. Several recent reviews and manuals of vegetation measurement techniques are available to the interested reader: Pieper (1973), Cook and Bonham (1977), Bonham and others (1980), and Knight (1978). Texts also of use include L. 't Mannetje (1978), Mueller-Dombois and Ellenberg (1974), Greig-Smith (1964), and Joint Committee of the American Society of Range Management and the Agricultural Board (1962). U.S. Department of Agriculture and U.S. Department of the Interior manuals that are available include the SCS National Range Handbook (1976), BLM Manual 4412.14, Soil-Vegetation Inventory Method (1979), and Forest Service Handbook 2209.21, Range Environmental Analysis (1968).

All terminology in this handbook adheres to the Society of Range Management (SRM) glossary of terms and the definitions in the permanent regulatory program for surface coal mining and reclamation operations.

Random Sampling Schemes

The sampling schemes outlined here—random, stratified random, and systematic sampling with multiple random starts—allow the calculation of a valid estimate of the variance of the mean. The specific scheme chosen depends on the parameter under investigation and on the sampling methodology used. Convenience, ease of implementation, and cohesiveness with the sampling methodology should be considered when deciding upon which scheme to use.

GENERAL CONSIDERATIONS

It is imperative that all sample points be objectively located within the sample unit. Knight (1978) states that three rules should always be followed:

1. Sample points should be distributed throughout the sample units and not just within a small portion of the sample unit.
2. Sample points should be located without any bias of the investigator.
3. Sample points should be located far enough within the sampling unit to avoid transition zones and the edge effect created by highways, rivers, and so forth.

The objective selection of random sample points is best accomplished with the use of a random numbers table.

USE OF RANDOM NUMBERS TABLES

A random numbers table is presented in appendix VI. Its use is outlined as follows:

1. An arbitrary, objective starting point is selected anywhere on the table, as long as it is not chosen because of the size of the number at that point.

Each digit within a random numbers table is a random number although random numbers are often given as four digits. If the bottom of column 2 in appendix VI were selected as a starting point, 4067, 406, 40, or 4 could be used as the first random number. The units of measure used for locating the sample points (paces, m, dm, and so forth) will determine the size of the number selected. The same sequence of numbers should always be selected, and zeros should be counted as one of the digits.

2. All subsequent random numbers are selected in the same manner as the first, progressing in order down the column.

RANDOM SAMPLE POINT LOCATION

The location of random sample points is depicted in figure 1.

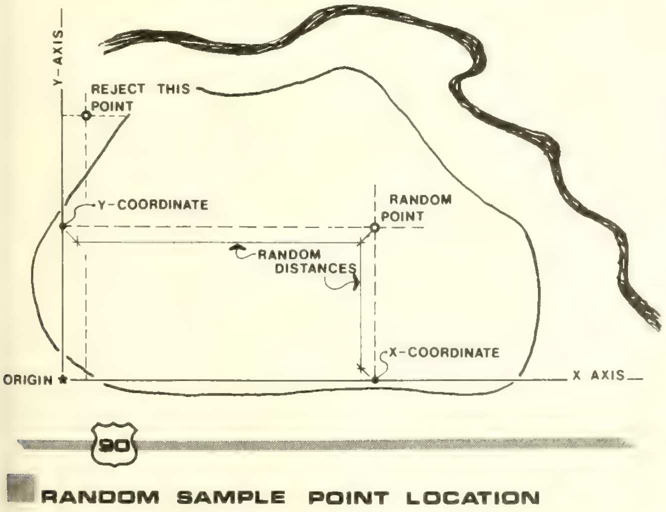


Figure 1.—Random sample point location (from Knight 1978).

The procedures for selecting random sample points are as follows:

1. Select two random numbers as described under the section on use of random numbers tables. The first number chosen is used as the distance along the x-axis and the second as the distance along the y-axis.
2. Locate the x-coordinate by pacing or measuring the random number distance along the x-axis from the point of origin. From the x-coordinate, pace or measure a line perpendicular from the x-axis and equal to the random number distance along the y-axis. The point at the end of the line is the random sampling point. A perpendicular line from the y-axis to the random sampling point should equal the distance along the x-axis. A sample point that falls outside of the sampling unit is not used.
3. Return to the point of origin, select the next two random numbers, and repeat the process described above. Continue this process until all sample points have been taken.

STRATIFIED RANDOM METHOD USING A BASELINE

The procedure for locating random sampling points using a baseline is shown in figure 2.

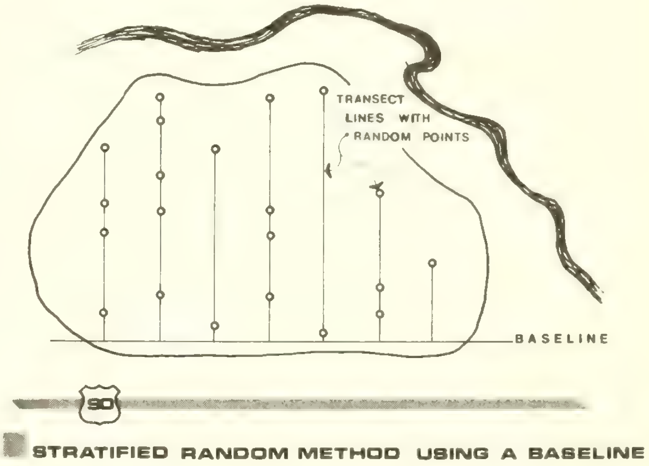

TRANSECT LINES WITH RANDOM POINTS
BASELINE
90
STRATIFIED RANDOM METHOD USING A BASELINE

Figure 2.—Stratified random method using a baseline (from Knight 1978).

1. Locate a baseline either through the middle or along one edge of the sampling unit. Points along this line will be spaced a predetermined and equal distance apart, such as 100 ft (30 m).
2. Proceed to the first point on the baseline and select a random number. This number is the distance to the first sample point along a line running perpendicular to the baseline. When the baseline is in the middle of the area and the random number is even, the sample point is on the right; if it is odd, the sample point is on the left.
3. Point 2 is obtained by choosing a second random number that is the distance to point 2 from point 1 along the same perpendicular line. Additional points are located in the same manner until the perimeter of the stand is approached. The investigator then returns to the baseline and proceeds to the second predetermined point. Sample points are then located along a line perpendicular to this point as described above. The procedure is repeated until an adequate sample has been collected.

Random numbers that result in the overlap of sample plots should be disregarded in most sampling situations. An occasional overlap of plots when using Bitterlich's variable radius method or the density quadrat method for shrubs does not decrease the validity of the data.

SYSTEMATIC SAMPLING WITH MULTIPLE RANDOM STARTS

Systematic sampling with multiple random starts is an efficient method of locating sample points that still allows a valid calculation of the variance of the mean, even though it utilizes systematic sampling (see Shiue 1960). This method can be implemented using a baseline and is similar to the stratified random method shown in figure 2. The procedures for establishing sample points using this method are as follows:

1. Locate a baseline either through the middle or along one edge of the sampling unit. Points along this line will be spaced a predetermined and equal distance apart.
2. Proceed to the first point on the baseline and select a random number. The random number is the distance to the first sample point along a line running perpendicular to the baseline (transect line).
3. Locate subsequent points a predetermined and equal distance apart along the transect line. Discontinue sampling along the transect line when the perimeter of the sample unit is approached.
4. Return to the baseline and proceed to the second predetermined point. Sample points are located along the transect line perpendicular to this point as described above. The distance to the first sample point is once again determined by the selection of a random number. Continue in this manner until an adequate sample has been taken, and the entire sample unit has been sampled.

If the baseline is placed in the middle of the sample unit, transects are placed on both sides of the baseline. A minimum number of random starts is six, but more are preferred.

Quadrat Size and Shape

Selecting the proper plot size and shape is very important for efficient sampling or sampling that will minimize both variance and sampling time. After reviewing the literature, Van Dyne and others (1963) presented the following generalizations concerning the influence of plot size and shape:

1. Perimeter-to-area ratios are lowest in circular plots and decrease as plot size increases. Low perimeter-to-area ratios generally decrease sampler error.
2. More species generally are included in long, narrow plots.
3. Optimum plot size and shape may depend upon the distribution of the species measured, with larger plots usually recommended in sparse vegetation.
4. Small sampling units, although generally more efficient statistically, often yield skewed data, and thus may not accurately represent the true population.
5. Greatest efficiency is generally indicated by smallest variance.
6. Random plot location is necessary for an unbiased estimate of variance.
7. To obtain an estimate of sampling error, an exclosure should contain more than one plot.

Both the type of vegetation community being sampled and the parameters being investigated will determine not only the plot size and shape, but also the specific methodology used. Table 1 presents the generalized vegetation types found in OSM Region IV and suggested quadrat sizes and shapes for use in each.

Table 1.—*Quadrat sizes for sampling production with circular, square or rectangular quadrat frames*

Vegetation type	Metric measure	American measure
Dense[1] tall-grass prairie and pastures	0.25-0.75 m^2	0.96-2.40 ft^2
Sparse[2] tall-grass prairie and pastures	.50-1.50 m^2	1.92-4.80 ft^2
Woodlands-dense understory	.75-1.50 m^2	2.40-4.80 ft^2
Woodlands-sparse understory	1.00-2.50 m^2	4.80-9.60 ft^2
Dense mid-grass prairie	.25-0.75 m^2	.96-2.40 ft^2
Sparse mid-grass prairie	.50-1.50 m^2	1.92-4.80 ft^2
Dense shrublands	.75-1.50 m^2	2.40-4.80 ft^2
Sparse shrublands	1.50-2.50 m^2	4.80-9.60 ft^2

[1] Dense is defined as ≥ 50% aerial cover.
[2] Sparse is defined as < 50% aerial cover.

Quadrat Sizes and Conversions

To convert grams per quadrat to pounds per acre:
- On 0.96 ft^2 quadrats, multiply grams by 100
- On 1.92 ft^2 quadrats, multiply grams by 50
- On 2.40 ft^2 quadrats, multiply grams by 40
- On 4.80 ft^2 quadrats, multiply grams by 20
- On 9.60 ft^2 quadrats, multiply grams by 10

To convert grams per quadrat to kilograms per hectare:
- On 0.25 m^2 quadrats, multiply grams by 40
- On 0.50 m^2 quadrats, multiply grams by 20
- On 0.75 m^2 quadrats, multiply grams by 13.33
- On 1.00 m^2 quadrats, multiply grams by 10
- On 1.50 m^2 quadrats, multiply grams by 6.67
- On 1.00 m^2 quadrats, multiply grams by 5
- On 2.50 m^2 quadrats, multiply grams by 4

Kilograms per hectare × 0.89235 = pounds per acre
Pounds per acre × 1.12064 = kilograms per hectare

Time of Sampling

In cases where sampling is intended to reflect the peak or maximum productivity, sampling should be timed to coincide with the seed-ripe or mature phenological stages of the majority of the species under investigation. At this stage the plants have accumulated the greatest biomass, and yield the highest amount of production.

Because the purpose of the sampling methodology described here is to compare two areas similar in life-form and seasonality, it is logical to obtain this comparison by sampling both areas during the same time interval and when the majority of the species are at the highest level of production. The sample does not necessarily need to reflect the *total* year's growth (production) of the community.

Numerous plant communities exist in which there is significant difference between the timing of flowering and seed production of the major species. Two examples of this are communities with both cool-season (perennial ryegrass) and warm-season (little and big bluestem) grasses, and communities with grasses that flower and mature long before the shrubs. Cool season plants generally make the major portion of their growth during the winter and early spring, and warm season plants make most or all of their growth during the spring, summer, or fall and are usually dormant in winter. In communities with varying seasonality, it may be necessary to sample when overall community production is at a peak. For the community with both cool-season and warm-season species, this would be at some point after which the cool-season grass had matured, but before it had dropped its seed. The warm-season grasses would likely be approaching maximum foliar growth and nearing anthesis or flowering. If the periods of peak production of the major species are extremely disparate, it may be desirable to sample at two different times to obtain an accurate estimate of total maximum productivity.

In some cases, it may be necessary to stagger sampling times between revegetated areas and reference areas, especially if the species are dissimilar and have different maturation times and phenologies. Each area must be sampled when the majority of its species are in the seed-ripe or mature phenological stages.

If the investigator wishes to obtain a value of total years production for the year, a separate phenological study can be initiated. This would involve sampling both areas at specified intervals (say, 2 weeks) throughout the growing season and collecting data on the dry-weight production of each species during each of its phenological stages. A method based upon this concept is described in BLM Manual 4412.

PRODUCTION SAMPLING CONCEPTS

Several definitions and various interpretations are available for the parameters of production, cover, and diversity. The definitions presented here were chosen to comply with the OSM regulations and to allow for the most efficient and accurate sampling and subsequent comparison of revegetated and reference areas.

Ideally, the vegetation investigator would sample net primary production, or the net increase in plant biomass (total energy content), which is incorporated into the aerial parts of the plant community within a specified area and time interval. Net primary production is very difficult to collect, however, and for the purposes of this handbook a simpler definition of production will be used that still provides accurate comparisons. The definition adhered to here is:

> "Vegetation production" is the current year's plant growth that consists of all green leafy vegetation, flowering stalks, seed-heads, and stems of herbs, and all green leafy vegetation, flowers, seeds and current year's twig growth of shrubs and trees. It also includes the persistent green, living leaves of evergreen species.

This definition does not apply when a revegetated area is compared to an approved standard. Such a comparison will require that the revegetated area be harvested or sampled in the same manner as the standard. It will be necessary to duplicate the exact methodology and to adhere to the same units of measure (bushels/acre or tons/acre) used to establish the standard if a valid comparison is to be made.

When the revegetated and reference areas have similar species composition and production data are to be used in the measurement of diversity, production should be sampled according to species. If the revegetated and reference areas differ in species composition, the production should be sampled by life-form. Table 2 presents the suggested life-form categories.

Table 2.—*Hierarchial life-form classification*

- I. Grasses and grasslike
  - A. Annual
  - B. Perennial
    - 1. Rhizomatous
      - a. Warm-season
      - b. Cool-season
    - 2. Bunch
      - a. Warm-season
      - b. Cool-season
- II. Herbs
  - A. Annual
  - B. Perennial
  - C. Biennial
- III. Shrubs and halfshrubs
  - A. Broadloaf
    - 1. Deciduous
    - 2. Evergreen
  - B. Needleleaf
    - 1. Deciduous
    - 2. Evergreen
- IV. Trees
  - A. Broadleaf
    - 1. Deciduous
    - 2. Evergreen
  - B. Needleleaf
    - 1. Deciduous
    - 2. Evergreen
- V. Lichens and mosses

For the purposes stated within this handbook, production will be measured at only one point in time.

Several standards need to be conformed to when obtaining production samples:

1. All production samples will be converted to dry weights and should be ovendried at 140° to 158° F (60° to 70° C). In areas characterized by high relative humidities, ovendrying is necessary to prevent wide fluctuations in dry weights and to obtain reliable, repeatable data.

2. Because production as defined here includes only current year's growth and living green leaves, it will be necessary to separate and remove all dead plant material not produced during the current growing season.

3. In order to standardize sampling and minimize sampler error, all vegetation will be harvested to ground level. If the production data are to be used for animal unit month (AUM) calculations, normal grazing height can be accounted for through proper use. Proper use is a degree and time of use of current year's growth that, if continued, will either maintain or improve pasture or range condition consistent with management goals.

4. Reference areas and revegetated areas will be sampled when the majority of the species have mature seeds.

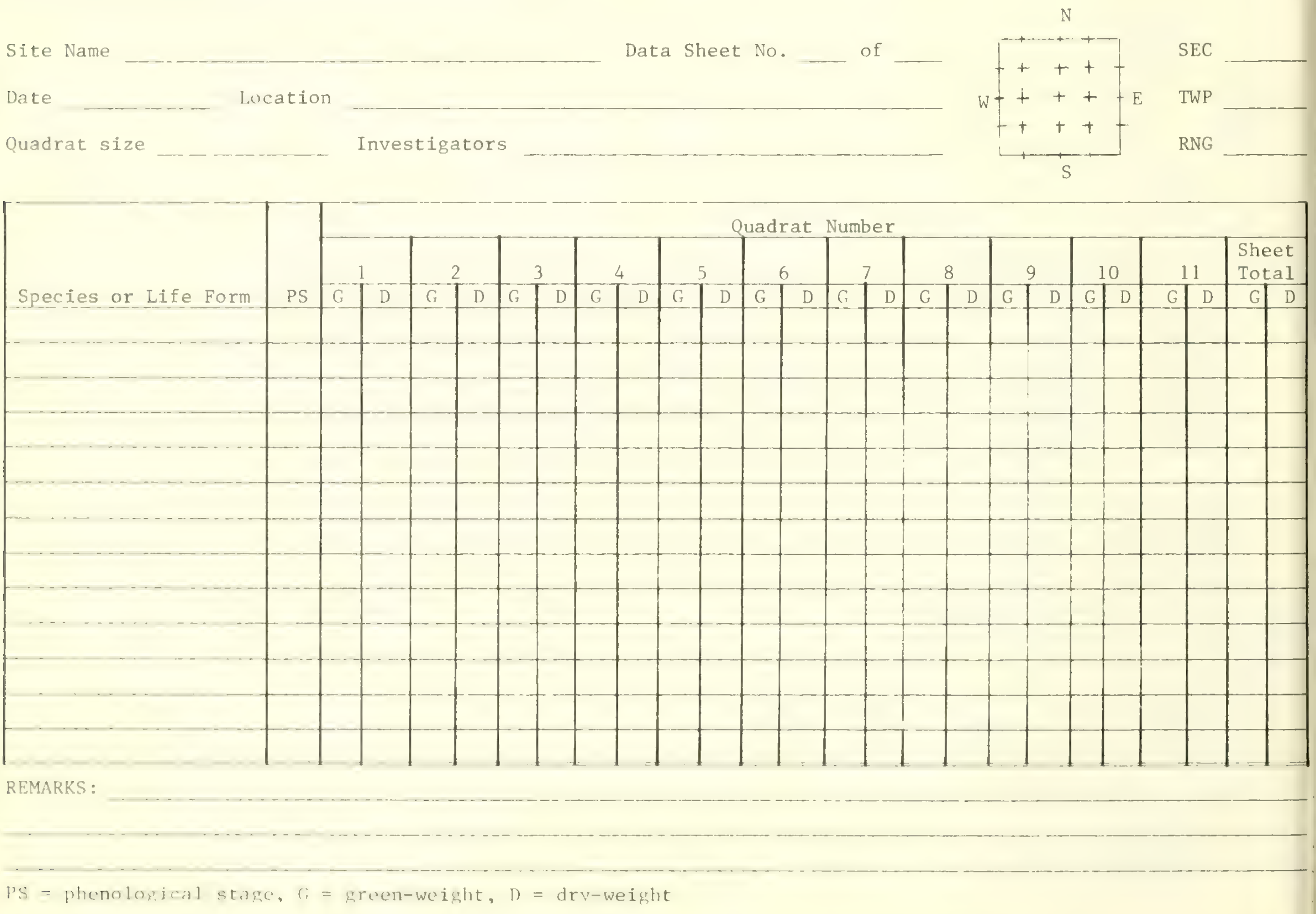
PRODUCTION SAMPLING METHODOLOGY

The methods here will provide investigators with the most reliable results and will allow them to meet the statistical limits required in the regulations. Either the harvest method or the weight-estimate method may be used in years prior to bond release; however, during the final year of sampling before bond release, the harvest method should be used. The quadrat size and shape will be determined by the vegetation type (see table 1). An explanation of how to determine the proper number of quadrats will be given in the section on statistics. Quadrat placement within the sampling unit should follow one of the three schemes outlined in the section on random sampling schemes.

Harvest Method

The harvest method involves clipping to ground level all of the vegetation within each quadrat by species or life-form. The procedures used are valid for both the harvest method and for double sampling. An example data form is shown in figure 3. The methods used are as follows:

1. The quadrat is placed on the ground within the sampling unit using a random sampling scheme. The orientation of square and rectangular quadrats must remain constant at each sampling location.
2. The vegetation within the quadrat is clipped to ground level using hand shears or clippers. Vegetation production, as defined earlier, is harvested from the three dimensional volume of the quadrat (height × width × length). Parts of plants that are rooted within the quadrat but do not occupy space within the volume are not harvested, while plants that are not rooted within the quadrat but overlap into the volume are harvested (see fig. 4). The volume method is generally accepted as the most accurate method for production clipping. However, in tall grass swards including only those plants rooted within the quadrat, regardless of quadrat volume, may be more efficient.
3. Vegetation is separated by species or life-form (see table 2), placed in paper bags, weighed, and labeled according to date, sampling unit, quadrat number, weight, and species or life-form. Green weights of species are necessary if sample size is to be calculated in the field and/or if double sampling is used. Phenological stage should be recorded by species if standing crop production is to be adjusted to peak annual production. Standard phenological stages are: (1) Beginning Growth, (2) Vegetative Stage, (3) Boot Stage (grass and grasslike), (4) Peak Flowering, (5) Soft Dough (grass and grasslike), (6) Seed Ripe, (7) Mature, (8) Dormant, and (9) Regrowth.
4. The vegetation samples are ovendried at 140°to 158° F (60°to 70° C) until a constant weight is obtained. Dry weights are then recorded by species or life-form for each quadrat. Weighing should be performed immediately after ovendrying to avoid absorption of water from humid air.
5. Total production and subsequent statistical computations are based upon the dry weights obtained in step 4. The calculations for production and percent composition of individual species or life-forms are:



Site Name ____________________ Data Sheet No. ____ of ____

Date ________ Location ____________________

Quadrat size ________ Investigators ____________________

SEC ______

TWP ______

RNG ______

Species or Life Form	PS	Quadrat Number																							
		1		2		3		4		5		6		7		8		9		10		11		Sheet Total	
		G	D	G	D	G	D	G	D	G	D	G	D	G	D	G	D	G	D	G	D	G	D	G	D

REMARKS: ____________________

PS = phenological stage, G = green-weight, D = dry-weight

Figure 3.—Data form for the harvest method.

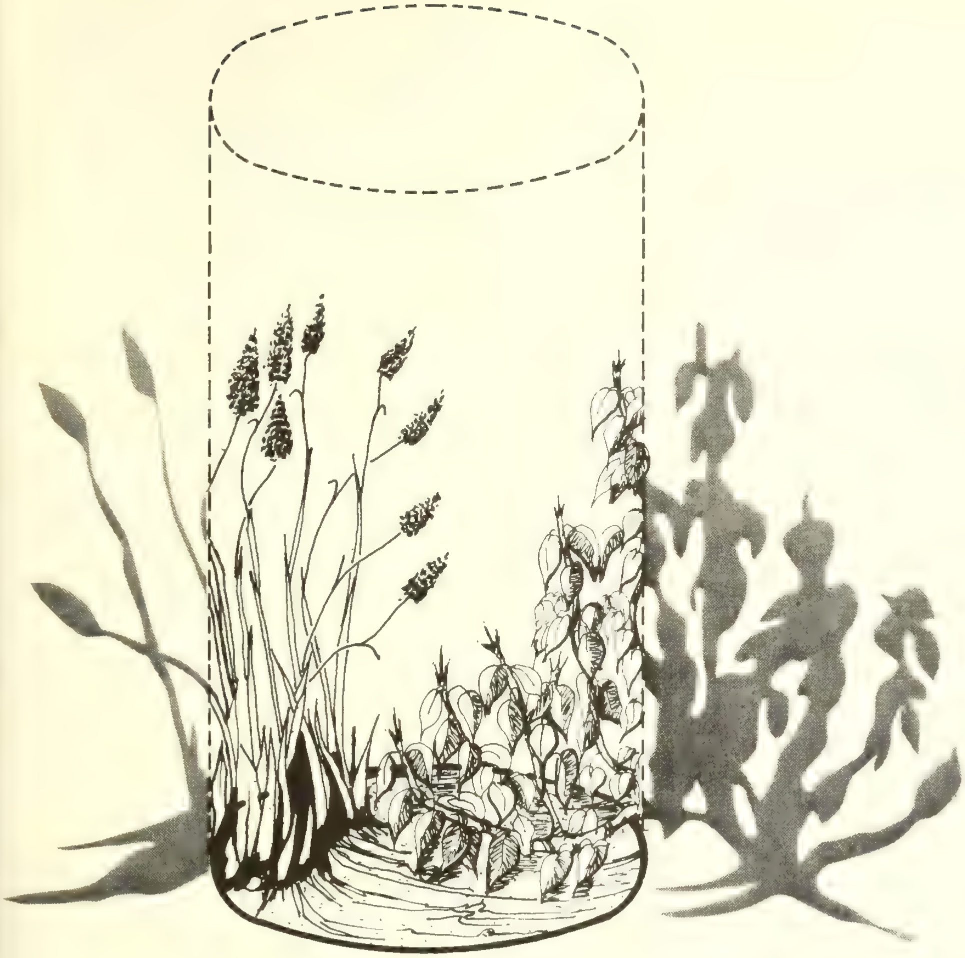


Figure 4.—Volume projection of a sample quadrat. Record only the weights of portions of plants inside the imaginary cylinder.

$$\text{Production} = \frac{\text{Total of dry weight values}}{\text{Total number of quadrats sampled}} \times \text{Quadrats per area conversion factor}$$

$$\text{Percent composition} = \frac{\text{Production for species or life form}}{\text{Total production for all species or life forms}} \times 100$$

Double-Sampling by the Weight-Estimate Method

Double-sampling using the weight-estimate method entails estimating vegetation production in a majority of the quadrats sampled and both estimating and harvesting production in the remainder of the quadrats sampled. This method allows the estimates of all the quadrats sampled to be corrected or adjusted for estimator error by techniques such as regression. Although this method may lack some of the precision and accuracy obtainable through the harvest method, it increases sampling efficiency or decreases the time and cost involved in sampling, especially when it is desirable to obtain production values by species. The increase in sampling efficiency may subsequently permit the sampling of a larger number of quadrats.

If the investigator chooses double sampling by the weight-estimate method, certain precautions need to be taken. Estimators require considerable training and must constantly check the accuracy of their own estimates if reliable data are to be obtained. There is some indication that estimates may generally be higher than actual values for quadrats with small yields and lower than actual values for quadrats with large yields. This means that the relationship between the estimated and actual clipped weights is probably linear only to a certain weight limit. This weight limit may be in the range of 100 to 120 grams per area of quadrat (Bonham and others 1980). It may therefore be advisable to use smaller quadrats when using the weight-estimate method.

Probably the most reliable method of weight estimation involves the consistent use of weight-units. The weight-unit consists of a representative part of the vegetation being sampled, such as a bunch of grass or a branch of a shrub. Two closely comparable weight-units of the same species are selected and the vegetation production of one is stripped or removed, weighed, and recorded. The remaining unit is then used as a comparison for counting the number of similar units within the sampling quadrat. The number of estimated units within the quadrat is multiplied by the recorded weight of the production removed from the stripped weight-unit to obtain the total estimated green weight. This procedure is repeated for each species in the quadrat. The same weight-units can be used in every quadrat as long as they represent the same growth form.

Estimators must be trained in the techniques of weight estimation. This involves clipping and weighing species within practice quadrats immediately after the entire quadrat has been estimated, and then adjusting individual estimation techniques. Ideally, an estimator would be within 10 percent of the actual clipped value for each species.

The procedural steps used for double sampling by the weight-estimate method are identical to those outlined under the harvest method except for the following differences:

1. The green-weight production within all quadrats is estimated prior to harvesting. An example of a data form for the weight-estimate method is shown in figure 5.
2. The numbers of the quadrats to be clipped are chosen from a random numbers table.
3. Exact quadrat locations should be marked and flagged after estimation so that they can be returned to for clipping. Vegetative material not included within the quadrat should be trimmed away from the quadrat frame in order to make quadrat relocation easier.
4. Species not included within the clipped quadrats but encountered within the estimated quadrats should be clipped from quadrats in which they do occur so that dry-weight conversion and estimator-error correction factors can be obtained.
5. To insure consistency and prevent bias, all quadrats within a sample should be estimated by the same person. The estimator should not be allowed to see the clipped weights of any quadrats within the sample until all plots have been estimated.

The calculations for deriving dry-weight production values from weight-estimate data are more involved than those for harvest data. The estimated green-weight values are corrected for estimator error and then adjusted to dry-weight values.

Two methods are available that use the actual and estimated green-weight values to adjust for estimator error. The first method derives a correction factor for each species by dividing the summed actual clipped weights by the summed estimated weights of the corresponding quadrats.

$$\text{Correction factor} = \frac{\Sigma \text{ clipped weight}}{\Sigma \text{ estimated weights}}$$

The correction factor is multiplied by the individual species value for each quadrat, or by the total species value summed for all of the quadrats.

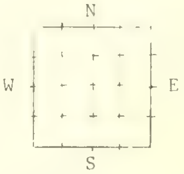
A second method involves the use of regression to obtain a predictive equation from which estimated weights can be adjusted. Individual species green-weight values for each quadrat, or individual quadrat values summed for all species, can be used for the clipped quadrats and their corresponding estimated quadrats. While the use of quadrat values summed for all species is not as accurate as the use of individual species values, it may, however, be difficult to obtain an adequate sample number for a regression for each individual species. In addition, calculating regressions for each species could potentially be time consuming.

An example given by Pieper (1973) is expanded upon here to illustrate the calculations involved. The estimated weights are

Site Name ____________ Data Sheet No. __ of __ SEC ____

Date ______ Location ____________ TWP ____

Quadrat size ______ Investigators ____________ RNG ____



		Quadrat Number (circle clipped quadrats)																														
		1					2					3					4					5					Clip #			Clip #		
Species	PS	G	CF	A	%D	D	G	CF	A	%D	D	G	CF	A	%D	D	G	CF	A	%D	D	G	CF	A	%D	D	G	D	%D	G	D	%D

REMARKS: ____________

PS = phenological stage, G = green-weight, CF = correction factor, A = adjusted green-weight, %D = percent dry-weight
D = dry-weight

Figure 5.—Data form for the weight-estimate method.

considered the independent variable (X) and the clipped weights are considered the dependent variable (Y). In this example, every five quadrats were estimated, clipped, and weighed:

Estimated weight (g)	**Actual clipped weight**
90	---
75	---
110	---
65	---
40	60
100	---
120	---
60	---
75	---
115	120

and so forth

The pairs of actual and estimated weights obtained are shown in table 3, where X^2, Y^2, and XY are given.

Table 3.—*Clipped (X) and estimated (Y) production values and corresponding values of X^2, Y^2, and XY*

	(clipped) X	X^2	(est.) Y	Y^2	XY
	60	3,600	40	1,600	2,400
	120	14,400	115	13,225	13,800
	100	10,000	95	9,025	9,500
	65	4,225	75	5,625	4,875
	95	9,025	80	6,400	7,600
	60	3,600	75	5,625	4,500
	100	10,000	110	12,100	11,000
	95	9,025	120	14,400	11,400
	85	7,225	60	3,600	5,100
	90	8,100	75	5,625	6,750
	120	14,400	115	13,225	13,800
Σ	990	93,600	960	90,450	90,725
Mean	90		87		

The first step is to calculate the corrected sums of squares and products. The corrected sum of squares for X:

$$\Sigma x^2 = \overset{n}{\Sigma} X^2 - \frac{\overset{n}{(\Sigma X)^2}}{n}$$

$$= 90{,}450 - \frac{(960)^2}{11}$$

$$= 6{,}668$$

The corrected sum of squares for Y:

$$\Sigma y^2 = \overset{n}{\Sigma} Y^2 - \frac{\overset{n}{(\Sigma Y)^2}}{n}$$

$$= 93{,}600 - \frac{(990)^2}{n}$$

$$= 4{,}500$$

The corrected sum of products:

$$\Sigma xy = \Sigma\,(XY) - \frac{(\Sigma X)\,(\Sigma Y)}{n}$$

$$= 90{,}725 - \frac{(990)\,(960)}{11}$$

$$= 4{,}325$$

The equation for a straight line is $Y = a + bX$. Use of the equation requires the assumption of a linear relationship between estimated weights and clipped weights. In the equation, a and b are constants or regression coefficients that must be estimated. According to the principle of least squares, the best estimates of these coefficients are:

$$b = \frac{\Sigma XY}{\Sigma x^2}$$

$$= \frac{4{,}325}{6{,}668}$$

$$= 0.65$$

$$a = \overline{Y} - b\overline{X}$$

$$= 90 - 0.65(87)$$

$$= 33.4$$

These estimates can be used in the general equation to obtain

$$Y = 33.4 + 0.65X$$

By substituting the estimated weights for x, a predicted or adjusted value can be obtained for each quadrat or species. This value will be used in all subsequent mathematical computations.

UTILIZATION SAMPLING

Utilization or use is defined in the SRM Glossary of Terms as "the proportion of current year's forage production that is consumed or destroyed by grazing animals." If utilization has occurred before sampling, it will be necessary to adjust the harvested or estimated production figures to their original values before grazing. Several methods have been developed to measure utilization, but the majority have been developed for grass species (see Pieper 1973). Although this information is equally valuable for shrub species, shrubs have been largely neglected due to the difficulties involved in finding suitable methodology for measuring utilization of their heterogenous growth form.

The estimation of percent utilization for grasses, forbs, or shrubs introduces additional error into the final production values obtained. The use of exclosures or the deferment of grazing until after sampling would eliminate this source of error in areas grazed by livestock.

Included here are a height-weight method for use with grasses and forbs, and, for shrubs, a discussion of the method of twig diameter and length of twig removed.

Height-Weight Method for Grasses

One of the most frequently used methods for determining percent utilization is based upon height-weight relationships. This method requires that the relationship between the amount of height removed and the corresponding amount of weight removed be determined for the grass and forb species under study. As shown for black grama in figure 6, this is seldom a linear relationship in grasses because the majority of the weight of a grass plant is at the base of the plant in its basal leaves.

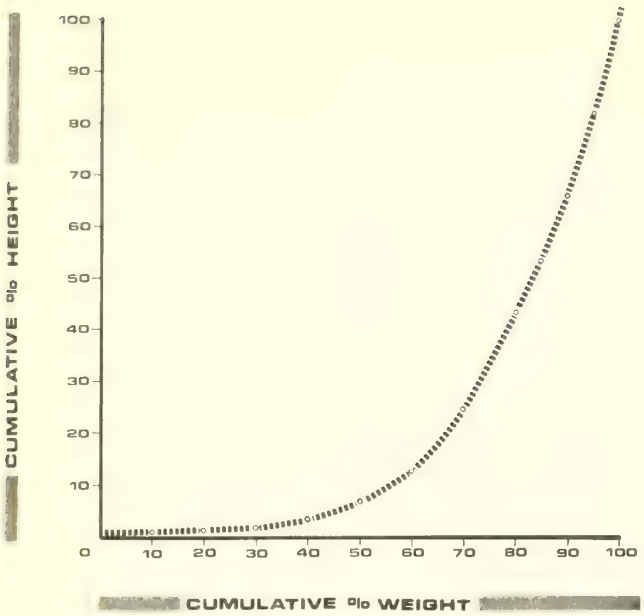


Figure 6.—Height-weight relationship for a 22-inch black grama plant (from Pieper 1973).

Extreme variation can exist in the height-weight relationships of different species of forbs.

The necessary height-weight relationships for the various species must be determined from ungrazed plants before sampling. This can be done in the field as a training excercise for estimators, and if desired, a table of height-weight relationships similar to table 4 can be constructed. For training individuals to estimate percent utilization, cumulative percent height and cumulative percent weight give the most relevant height-weight relationships.

If it is known that grazing will precede sampling, cages should be installed to protect a sufficient number of plants for determining height-weight relationships and for training estimators. The general procedure for determining height-weight values is to clip a number of plants (say, 10) into 1- or 2-inch (2.5- or 5-cm) segments either in the field or in the lab. If the plants are taken into the lab, a convenient method for grasses is to tie individual plants with string at the desired increments and clip them at ground level. After the individual increments have been separated and weighed, the height-weight relationships are determined. This information is used by the estimator to determine the percent of utilization by species for each individual sampling quadrat. If the harvest method is used, percent utilization must be estimated and recorded before clipping. When the weight-estimate method is used, production is estimated on the basis of the amount of vegetation material in the quadrat at the time of estimation. Adjusted total production values are calculated from estimated or clipped green-weight values and percent utilization.

$$\text{Adjusted total production} = \frac{\text{Estimated or clipped weight}}{\text{100-percent utilization}}$$

Percent utilization is determined on a green-weight basis, and the calculation of adjusted total production precedes the computation of predicted or adjusted green weight and dry weight.

Shrub Utilization

Statistically reliable techniques for correcting sampled shrub production to total production after utilization currently do not exist. The following section discusses methods that have been used, their weaknesses, and their application to sampling of revegetated and reference areas.

The majority of the literature on utilization of shrub species has dealt with developing methods for determining the percent use of the most recent twig growth, or leaders, of the key browse species utilized by big-game ungulates and livestock. Strong correlations exist between twig diameter and weight and length (Smith and Urness 1962; Basile and Hutchings 1966; and Jensen and Urness 1980). If the relationship between twig diameter and weight or twig length and weight is known, it is possible to determine the percent utilization by weight from (1) twig tip diameter, basal diameter, and browsed-tip diameter, or (2) the original leader length and the leader length after browsing. The problem with using twig reduction methods as an index to utilization is that leaves that are removed from other portions of the plant, and twigs that are stripped but not

Table 4.—*Height-weight relationship of a 22-inch black grama plant on the college ranch (Pieper 1973)*

Height	Increment	Weight	Height	Cumulative height	Weight	Cumulative weight
Inches		*Grams*	*Percent*			
19.8–22.0	2.2	0.2	0.10	10	0.32	0.32
17.6–19.8	2.2	.4	10–20	20	.63	.95
15.4–17.6	2.2	.6	20–30	30	.95	1.90
13.2–14.4	2.2	1.0	30–40	40	1.58	3.48
11.0–13.2	2.2	2.0	40–50	50	3.17	6.65
8.8–11.0	2.2	3.8	50–60	60	6.02	12.67
6.6–11.0	2.2	7.5	60–70	70	11.88	24.55
4.4–6.6	2.2	11.6	70–80	80	18.37	42.92
3.3–4.4	1.1	6.2	80–85	85	9.82	52.74
2.2–3.3	1.1	8.1	85–90	90	12.83	65.57
1.1–2.2	1.1	10.2	90–95	95	16.16	81.73
0–1.1	1.1	11.6	95–100	100	18.22	99.95
	22.0	63.1			99.95	

removed, are not taken into account. The relationship between twig diameter and weight and length varies greatly among species, and it is necessary to develop separate regressions for each species.

If the investigator does find it necessary to adjust for shrub utilization, the twig diameter or length of twig removed methods for shrubs can be used. For detailed descriptions of these methods, refer to the above literature citations. The generalized procedures for this particular sampling situation are given here.

Regression equations in which twig diameter or twig length was the independent variable and twig weight was the dependent variable would be developed by species. It may be possible to obtain the required measurements for developing the regressions from ungrazed twigs or leaders. However, to insure an adequate sample size, it is advisable to cage or exclose several (10) individuals of the key use species prior to grazing. Measurements of either the remaining leader length or the browsed-tip diameter and basal diameter would be taken for each sample quadrat in which the shrub species had been utilized. This data would then be used in the appropriate regression equation to obtain a predicted or adjusted total production value.

COVER SAMPLING CONCEPTS

Ground cover is defined in the regulations:

> **Ground cover** is the area of ground covered by the combined aerial parts of vegetation and the litter that is produced naturally on site, expressed as a percentage of the total area of measurement (CFR 816.116(d)(3)).

Aerial parts can be interpreted as all aboveground living plant material. Figure 7 depicts the difference between aerial cover or maximum spread of the foliage and basal area. Standing dead material, other than current year's growth, should be included in the litter category as should dead fallen organic material.

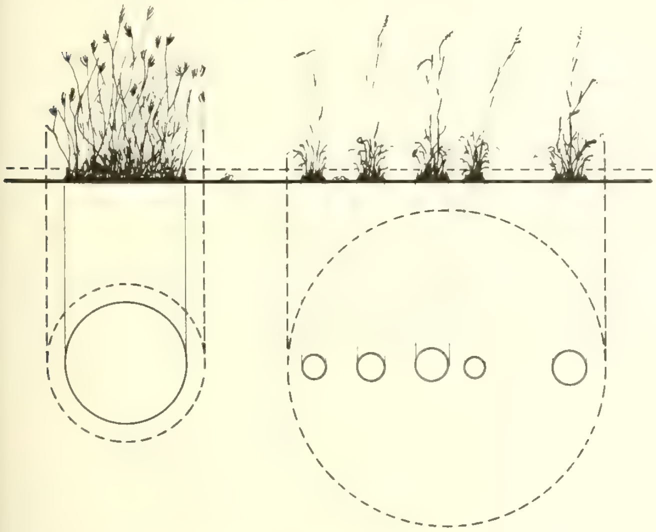


Figure 7.—*Aristida purpurea* (left) and *Bouteloua gracilis* showing the difference between maximum spread of the foliage (aerial cover) and basal area.

Comparison of the cover of a revegetated area to an approved standard will require sampling the revegetated area with the same methods and units of measure that were used to establish the standard. Cover data may be collected by species or life-form, but should be consistent with production and diversity methodology.

In addition to living plant material and litter, bare ground, gravel 0.25 to 3 inches (0.6 to 7.6 cm), and rock >3 inches (7.6 cm) will be recorded. They require little extra effort and provide important site information because they contribute to soil surface protection from raindrop impact and other erosional processes.

Cover is only a valid comparative measure when both the reference and the revegetated areas have received equal levels of utilization or none at all.

COVER SAMPLING METHODOLOGY

Numerous methods are available for estimating vegetation cover (see Pieper 1973). Several studies have shown that the point-quadrat and line-intercept methods are generally the most accurate in estimating the actual cover of herbaceous and shrubby vegetation. They exhibit reasonably low variability between sample quadrats. A relatively recent innovation with a high degree of accuracy involves determining cover from 35mm slides of individual sample quadrats. An accurate and efficient method for estimating basal area of tree stands is Bitterlich's variable radius method. The methodology, specific use, and limitations of these three methods are given here. Determination of the number of samples necessary to achieve statistical adequacy is explained in the section on statistics. Locating samples within the sampling unit should be based upon one of the schemes outlined in the section on random sampling schemes.

Point-Quadrat Method

The point-quadrat method can be used as a nondestructive method for determining aerial and/or basal cover and the layers of vegetation cover within a community. (An example data form is shown in figure 3.) The methods used are as follows:

1. A point or pin frame with multiple pins (10 are frequently used) is randomly located within the sampling units (see fig. 8).

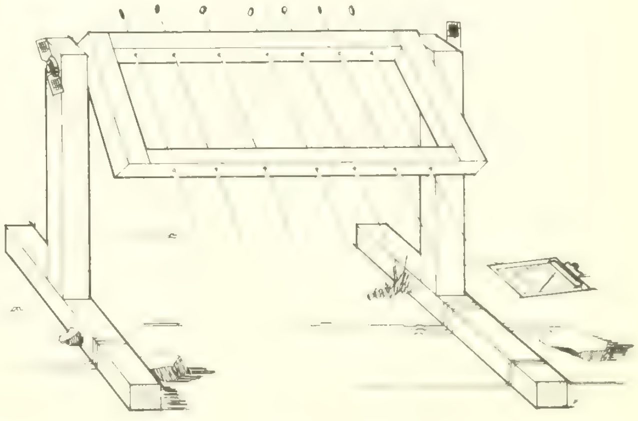


Figure 8.—A point frame device.

2. The individual sharpened pins are lowered down through the vegetation canopy. Each contact with the pinpoint is recorded by species or growth-form (see fig. 9). If a pin hits the same species more than once, only the first contact is recorded. Basal hits are recorded by species or growth-form or as bare ground, gravel, rock, litter, and moss or lichens. Depending upon the information desired, the investigator may record only the first vegetation contact and/or the basal hit.

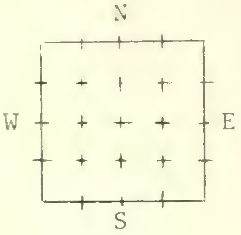
Site Name ______________________

Date ____________ Location ______________________

____

Sample size ____________ Investigators ______________________

____



SEC ______

TWP ______

RNG ______

GROUND COVER DATA

BASAL	CATEGORY	DOT	COUNT	NO.
B	Bare Ground			
P	Persistent Litter			
N	Non-Persistent Litter			
G	Gravel (2mm-3")			
R	Rock (>3")			

Record ground cover category and/or species symbol of each successive hit. Single hits on ground cover need only be recorded above.

BASAL	CANOPY 1	CANOPY 2	CANOPY 3	DOT COUNT NO.	BASAL	CANOPY 1	CANOPY 2	CANOPY 3	DOT COUNT NO.
TOTAL NUMBER POINTS					TOTAL NUMBER POINTS				

Work Area/Remarks

Figure 9.—Data form for the point quadrat method.

3. The sample size required to obtain statistical adequacy is usually 100 to 300 pins. A method for determining the exact sample size is given in the section on statistics.

4. The data are summarized either by frame (the 10 pins) or by transect for statistical analysis.

5. Several cover values can be derived from this information:

a. Percent aerial cover for each species or life-form equals the sum of all first hits on that species or life-form divided by the sum of all first hits on vegetation, plus first hits on bare ground, gravel, rock, litter, and moss or lichens.

b. Percent total aerial cover equals the sum of all first hits on vegetation divided by the sum of all first hits on vegetation plus all first hits on bare ground, gravel, rock, litter, and moss or lichens. Values for the individual components of basal cover (vegetation, bare ground, rock, gravel, litter, and moss or lichens) can be calculated in a similar manner.

c. The percent vegetation cover by species equals the total number of canopy hits by species or life-form divided by the total number of canopy hits.

Additional considerations for point-quadrat sampling are:

1. The frame should be held vertically for measuring cover. Frames placed at an angle may result in an increase in the number of interceptions and in an overestimate.

2. The dimensions of the frame should accommodate the height and spacing of the plants to be sampled. A typical frame is 3 ft (0.9 m) high and 3 ft (0.9 m) long with wire pins or steel rods placed 4 inches (10 cm) apart and the same length as the legs. It should have two guide bars to slide the pins through to minimize sample bias.

3. The pin or rod must be sharp, as dull or blunt pins may result in an overestimate.

4. This method cannot be used when vegetation is moving in the wind.

5. The frame should be built so that the pinpoint does not vibrate when the pins are moved.

This method is best suited for sampling normally sized 8 to 20 inches (20 to 50 cm) tall, herbaceous or dwarf shrub vegetation. It should not be used in shrubby vegetation.

Line-Intercept Method

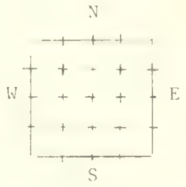
The line-intercept method can be used to measure aerial cover of plants with fairly solid crown cover (almost 100 percent) or relatively large basal areas. It is best suited for measuring aerial cover of woody plants, shrubs, and trees. (A suggested data form is presented in figure 10.) The methodology is as follows:

1. A line of predetermined length, preferably a tape measure, is stretched tightly across the vegetation. The line should be objectively located. The best sampling procedure is the stratified-random sample using a base line and perpendicular transects.

Site Name ______________ Data Sheet No. ___ of ___

Date ________ Location ______________

Line Length ________ Investigators ______________



SEC ______

TWP ______

RNG ______

Species	Line Number					
	1	2	3	4	5	Total

Figure 10.—Data form for the line intercept method.

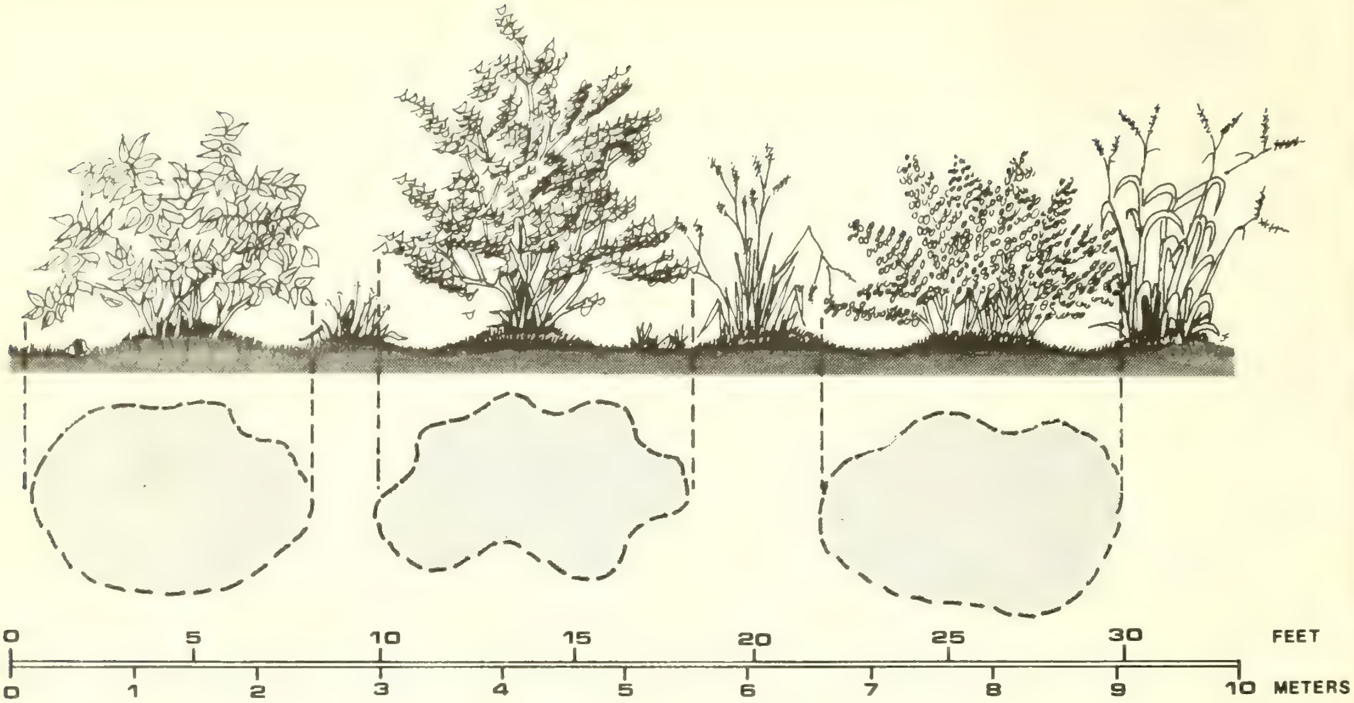


Figure 11.—Use of the line intercept method.

2. The canopy intercept of each species along the line is measured from the tape or with a rule. This procedure is shown in figure 11. If the canopies overlap in layered vegetation, it may be desirable to measure each height layer separately.

3. Transect lines should be between 35 and 350 ft (10 m and 100 m) in length. Many short lines are generally preferred to a few long lines. A minimum of about 5 to 10 transects are usually required for an adequate sample. (Determinination of an exact sample size is explained under the section on statistics).

4. Data are summarized by transect line for statistical analysis.

5. Percent cover is calculated for each transect by species. The length intercepted by a species is divided by the transect length and multiplied by 100. The percent cover of a species by sampling unit is determined by dividing the sum of the individual transect lengths intercepted by the total transect length sampled then multiplying by 100.

Special considerations for this method are:

1. The line-intercept method should only be used for vegetation with well-defined canopies. In mixed communities of grasses and shrubs, it may be desirable to use the point-quadrat method for herbaceous vegetation and the line-intercept method for shrubs. The point-quadrat frames could be randomly located along the transect line used to measure shrub cover.

2. Data must be clearly recorded so that each shrub interception can be separated. It may be desirable to add additional lines for recording values to the line-intercept data form.

3. If the canopies of individual plants are not always solid, their interception along the tape should be consistently interpreted. For example, when a shrub has bushy branches that reach across the tape with gaps in between, the gaps should not be measured. Small within-plant gaps are best ignored.

35mm Slide Method

The 35mm slide method is an accurate means of determining the aerial cover of vegetation. Individual sample quadrats are first photographed in the field. Later, the percent of the quadrat covered is determined from a grid onto which the developed slide is projected. The methods used are as follows:

1. Sample quadrats are randomly located in the sample area using any one of the random sampling schemes previously described. The same quadrats used to photograph cover can be used to sample production, but cover must be photographed before production is sampled.

2. The quadrat is labeled according to the location, date, and quadrat number. Labeling can be accomplished with individual cards for each quadrat, or a film imprinting system such as the Recordata Back available for Olympus cameras can be used.

3. A tripod and camera bar are used to position the camera vertically over the center of the quadrat. A camera bar can be constructed that mounts on the tripod perpendicular to the ground. On one end of the bar a screw-mount for attaching the camera can be positioned. On the other end of the bar a counter-weight equivalent to the weight of the camera can be affixed.

The size of the camera lens used should be determined by the size of the quadrat. When viewed through the lens, the quadrat should encompass the majority of the area outlined in the lens without distortion.

4. The focus, lens aperture, and shutter speed is adjusted for each quadrat and the photograph is taken.

Analysis of the processed film proceeds as follows:

5. The slide is projected onto a grid with 100 squares. The vertical and horizontal axes of the grid must have the same

proportionate lengths as the vertical and horizontal axes of the quadrat frame. The slide projector is adjusted so that the area within the quadrat exactly matches that within the grid.

6. The number of grid squares covered by vegetation, litter, bareground rock, and gravel are counted. The number of squares counted is equivalent to the percent of each cover category within the sample grid.

In sparse communities where individual plants can be identified from the slide, it may be possible to obtain percent cover by species.

7. Data are summarized by quadrat for statistical analysis. Percent cover values can be derived for each of the cover categories (total vegetation litter, bareground rock, and gravel). In some cases percent cover can also be determined for life forms and or species.

Other considerations for the use of this method are:

1. The 35mm slide method is not well suited to sampling schemes that involve large quadrat sizes. Quadrats larger than about 0.5 m^2 cannot easily fit within the area encompassed by standard lens sizes.

2. This method is not well-suited to tall vegetation (over 1 m). In mixed communities of grasses and shrubs the 35mm slide method can be used to assess grass and forb cover, and the line-intercept method can be used to evaluate shrub cover.

Bitterlich's Variable Radius Method

The Bitterlich method is an efficient means of obtaining basal area and density of tree species. It is a plotless method of selecting sample trees on the basis of size rather than frequency of occurrence. (See Hovind and Rieck 1970; Mueller-Dombois and Ellenburg 1974; Dilworth 1964; and Avery 1967.) A point sample is used and trees are selected for tallying with the use of an optical wedge, prism, or angle gage. The probability of tallying any given tree is proportional to its stem basal area (BA). Trees may be thought of as being encircled by imaginary zones proportional to stem diameter. These zones determine which trees are tallied (see fig. 12). The sighting angle used is based upon the average size and distribution of the trees in the stand. Each sighting angle has a corresponding basal area conversion factor (BAF), which allows the calculation of basal area and density. Table 5 lists the common basal area factors and angle sizes used in point sampling. An example data form is presented in figure 13. The methods used are as follows:

1. Trees are tallied in a complete circle around the investigator using an optical wedge, prism, or angle gage of a preselected basal area factor (BAF) by 2-inch (5-cm) diameter class. Optical wedges or prisms are held directly over the sampling point. If an angle gage is used, the crosspiece is held over

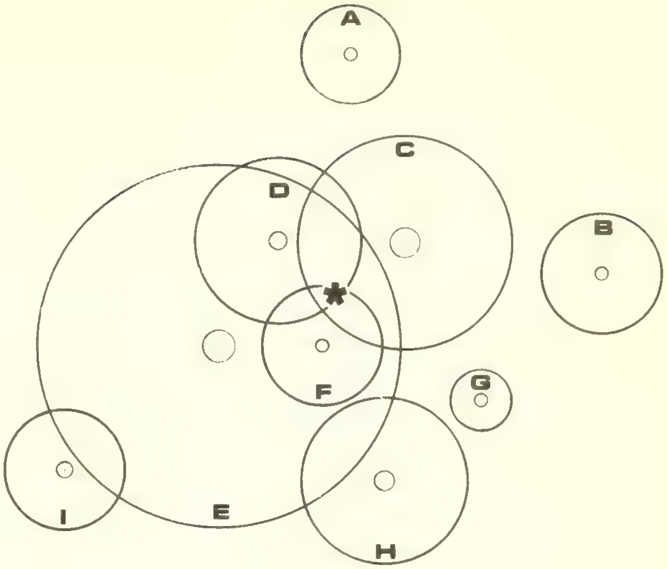


Figure 12.—Imaginary zones proportional to stem diameter and encircling each tree determine which trees will be tallied at a given point (from Hovind and Rieck 1970).

Table 5.—*Common basal area factors and angle sizes used in point sampling*

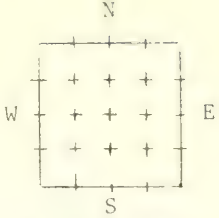
Basal area factor	Angle size, min	Angle size, diopters	Ratio (tree diameter to plot radius)	Plot radius factor
1	32.94	0.96	1/104.4	8.696
2	46.59	1.36	1/73.8	6.149
3	57.06	1.66	1/60.2	5.021
4	65.89	1.92	1/52.2	4.348
5	73.66	2.14	1/46.7	3.889
10	104.18	3.03	1/33.0	2.750
15	127.59	3.71	1/26.9	2.245
20	147.34	4.29	1/23.3	1.944
25	164.73	4.79	1/20.9	1.739
30	180.46	5.25	1/19.0	1.588
35	194.92	5.67	1/17.6	1.470
40	208.38	6.07	1/16.5	1.375
50	232.99	6.79	1/14.8	1.230
60	255.23	7.44	1/13.5	1.123

From Hovind and Rieck 1970.

Site Name ______ Data Sheet No. ____ of ____

Date ______ Location ______

Basal Area Factor ______ Investigators ______



SEC ____

TWP ____

RNG ____

Two-Inch Dia. Class	Point Number																Mean Tally	BA Per Acre*	BA Per Tree	Trees Per Acre
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16				
2																			0.022	
4																			0.087	
6																			0.196	
8																			0.349	
10																			0.545	
12																			0.785	
14																			1.069	
16																			1.396	
18																			1.767	
20																			2.182	
22																			2.640	
24																			3.142	
26																			3.687	
28																			4.276	
30																			4.909	
32																			5.585	
34																			6.305	
36																			7.069	
Totals																				

*square feet

REMARKS: ______

Figure 13.—Data form for the Bitterlich variable radius method.

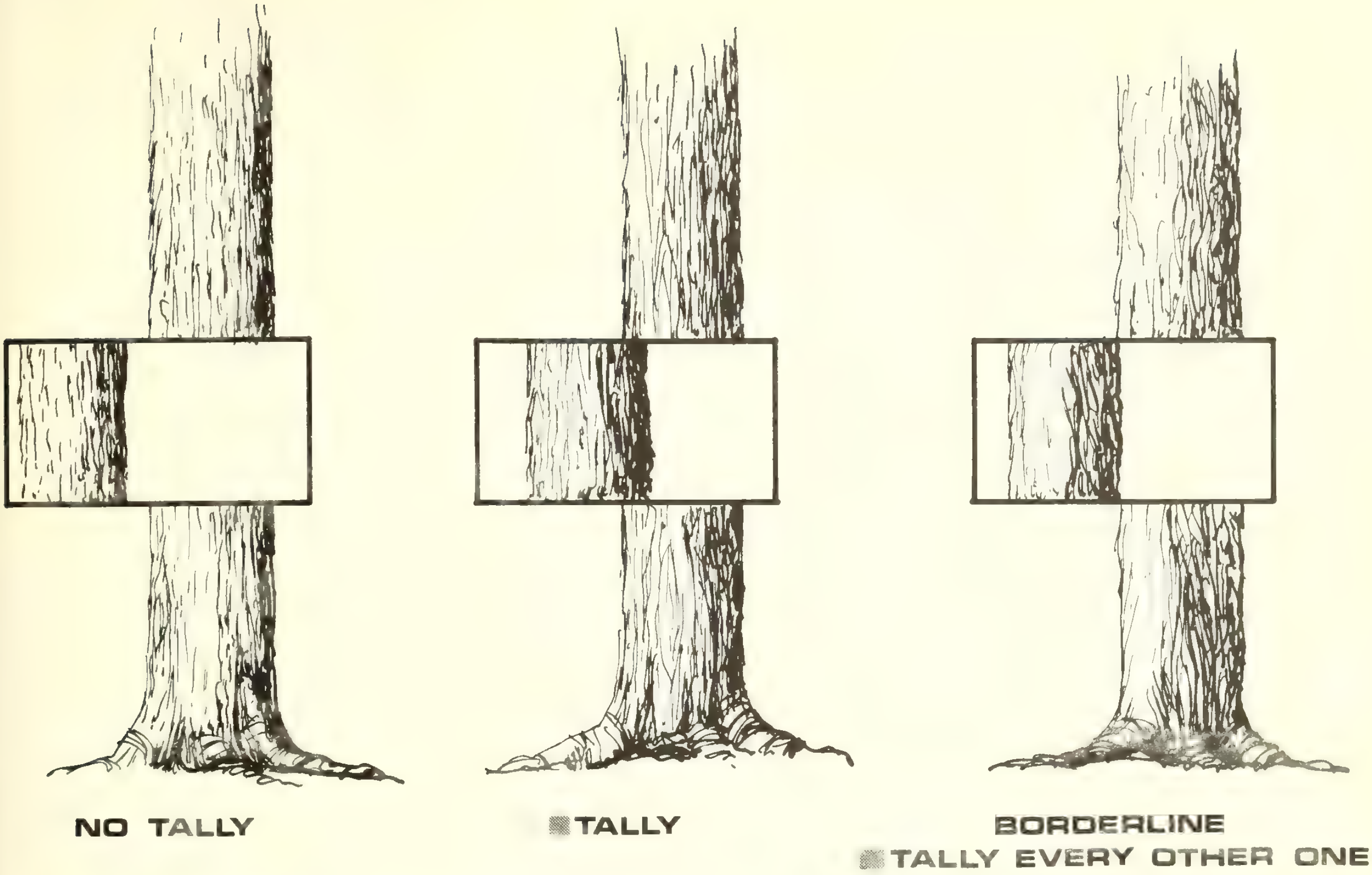


Figure 14.—Use of the optical wedge or prism for point sampling (from Avery 1967).

the point. When using the wedge or prism, a tree is counted when its stem is not completely offset when viewed through the wedge. All other trees are ignored (see fig. 14). If a stick-type angle gage is used, all trees larger than the defined angle (crosspiece) are counted and those that are smaller are ignored. In both cases, borderline trees should be tallied as a half tree.

Trees should be tallied by species. All trees should be sighted at breast height. The same tree may be tallied from two different sample points; however, points should be spaced widely enough so this occurs infrequently.

2. In sloping terrain, compensation must be made for the effect slope has in decreasing the sighting angle. There is no method available for correcting for slope with the stick-type angle gage. An abney or clinometer can be used in correcting for slope when using the optical wedge or prism. If an abney is used, the slope angle is measured and "locked in." The abney is then held level, the prism or optical wedge is placed on the sloping angle of the abney, and trees are tallied while viewing the prism or wedge held on the sloping angle. When a clinometer is used, the slope is determined and the clinometer is held at the angle of the slope. The prism or optical wedge is placed on the sloping angle of the clinometer, and trees are tallied from this angle. Each tree to be tallied requires a new measurement of slope.

An instrument that can be used instead of the wedge, prism, or angle gage and that automatically corrects each angle for slope is the Spiegal relascope. Sighting angles are provided for basal area factors of 5, 10, 20, or 40. The convenience of the Spiegal relascope may be outweighed by its expense, however, and it does not have the optical qualities for good visibility on dark and rainy days.

3. The number of trees tallied will be dependent upon the BAF and its corresponding sighting angle. The average size and distribution of the trees in the sample unit determine the selection of a BAF. A sampling unit with numerous small trees should be sampled with a narrow sighting angle (small BAF). A narrow sighting angle extends a greater distance to include trees of smaller diameter (see fig. 15). In stands with large tree diameters, the angle is increased (large BAF) to prevent extremely large tallies. The BAF is normally selected so that 5 to 12 trees will be tallied at each sample point.

The BAF is determined for stick-type angle gages by the width of the crosspiece and the length of the angle gage (stick). Table 6 gives the relationships between the width of the crosspiece and the length of the angle gage. It is possible for the investigator to construct angle gages for a specified BAF using these relationships. Such gages should be calibrated for each sampler. (The calibration technique is described in a later section.)

4. For statistical analysis, the data should be summarized by sample point regardless of diameter class.

5. The computations for determining mean tally, basal area (BA) per acre, and the number of trees per acre for each 2-inch diameter class are:

$$\text{Mean tally} = \frac{\text{No. of trees tallied per diameter class}}{\text{Total no. of sample points}}$$

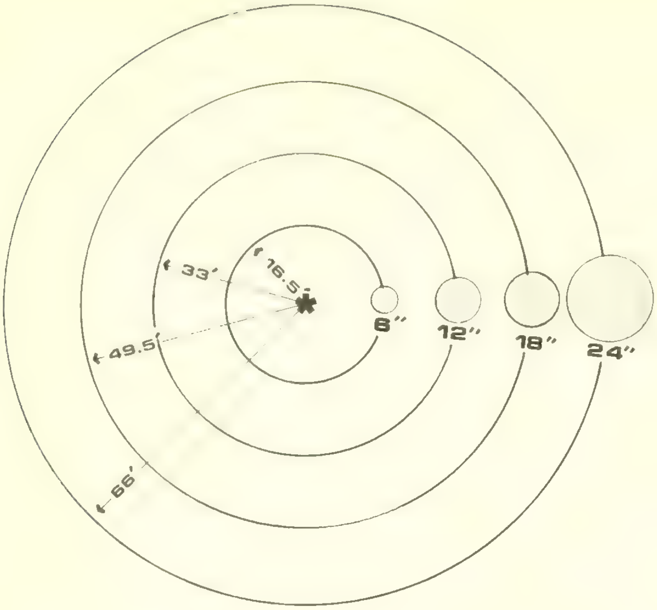


Figure 15.—Ratio of tree diameter to plot radius for BAF 10 (from Hovind and Rieck 1970).

Table 6.—*Relationships between crossarm and length of angle gage*

Width of crossarm	Length of angle-gage BAF 5	 BAF 10	 BAF 20
		Inches	
0.25	11.67	8.25	5.83
.30	14.00	9.90	7.00
.35	16.33	11.55	8.17
.40	18.67	13.20	9.33
.45	21.00	14.85	10.50
.50	23.34	16.50	11.67
.55	25.67	18.15	12.83
.60	28.00	19.80	14.00
.65	30.34	21.45	15.16
.70	32.67	23.10	16.33
.75	35.00	24.75	17.50
.80	37.34	26.40	18.66
.85	39.67	28.05	19.83
.90	42.00	29.70	21.00
.95	44.34	31.35	22.16
1.00	46.67	33.00	23.33

BAF 5 has a ratio of 1/46.67; therefore length of stick is 4.667 inches per 0.1 inch of crossarm.

BAF 10 and 20 have ratios of 1/33 and 1/23.33; therefore length of stick is 3.300 inches and 2.333 inches per 0.1 inch of crossarm respectively.

From Hovind and Rieck 1970.

$$\text{Basal area per acre} = \text{No. of trees tallied} \times \text{BAF}$$

$$\text{No. of trees per acre} = \frac{\text{Basal area per acre}}{\text{Basal area per tree}}$$

Total BA per acre, total number of trees per acre, and mean tree size per acre are calculated as follows:

$$\text{Total basal area per acre} = \text{Total no. trees tallied} \times \text{BAF}$$

$$\text{Total no. trees per acre} = \text{Sum of no. of trees per acre in each diameter class}$$

$$\text{Mean tree size per acre} = \frac{\text{Total basal area per acre}}{\text{Total no. trees per acre}}$$

An example of the summary data calculations is given in table 7 and related information is found in table 8.

Table 7.—*Example of summary data calculations for the Bitterlich's variable radius method. Basal area factor equals 25*

Two-inch diameter class	Mean tally	Basal area per acre	Basal area per tree*	Trees per acre
6	1	25	0.196	127
8	2	50	.349	143
10	3	75	.545	138
12	1	25	.785	32
Total	7	175		440

$$\text{Basal area per acre} = (\text{No. tallied trees}) \times \text{BAF} = 7 \times 25 = 175 \text{ ft}^2/\text{acre}$$

$$\text{Total trees per acre} = \frac{\text{basal area/acre}}{\text{basal area/tree}} = \frac{25}{0.196} = 127$$

$$\text{Mean tree size per acre} = \frac{175}{440} = 0.3977 \text{ ft}^2 \text{ basal area}$$

$$= 8.5 \text{ inches diameter}$$

*From table 8

Additional information concerning this method is given below:

1. Angle gages, prisms, and optical wedges are readily available from most scientific supply houses, such as Ben Meadows Forestry, Engineering and Educational Supples, 3589 Broad St., Atlanta (Chamblee), GA 50366; and Forestry Suppliers, Inc., 205 West Rankin St., Box 8397, Jackson, MS 39204. (These addresses are provided solely for information and not for advertising purposes.)

2. If angle gages, prisms, or optical wedges of unknown quality are obtained and the exact BAF is unknown, the instrument must be calibrated. Because sighting habits of individual samplers vary, it is often desirable to calibrate all instruments regardless of price or supposed precision. Calibration is accomplished by placing a circular target of known diameter such as

Table 8.—*Derivation of the basal area factor of 10 ft² per acre for point sampling*

Tree dbh. (1)	Imaginary plot radius, (2)	Imaginary plot size (3)	Trees per acre,* No. of stems (4)	Basal area per tree (5)	Basal area per acre, (6)
Inches	*Feet*	*Acres*		----------- *Ft²*	-----------
4	11.00	0.0087	114.94	0.087	10
6	16.50	.0196	54.02	.196	10
8	22.00	.0349	28.65	.349	10
10	27.50	.0545	18.35	.545	10
12	33.00	.0785	12.74	.785	10
14	38.50	.1069	9.35	1.069	10
16	44.00	.1396	7.16	1.396	10
18	49.50	.1767	5.66	1.767	10
20	55.00	.2182	4.58	2.182	10
22	60.50	.2640	3.79	2.640	10
24	66.00	.3142	3.18	3.142	10
26	71.50	.3687	2.71	3.687	10
28	77.00	.4276	2.34	4.276	10
30	82.50	.4909	2.04	4.909	10
32	88.00	.5585	1.79	5.585	10
34	93.50	.6305	1.59	6.305	10
36	99.00	.7069	1.41	7.069	10
Method of calculation	dbh × 2.75	$\frac{\pi r^2}{43,560}$	$\frac{1.00}{\text{plot size}}$	$0.005454D^2$	column 4 × 5

*Exact value for number of trees per acre may vary slightly, depending upon number of decimal places expressed for imaginary plot size.
From Hovind and Rieck 1970.

1 ft (0.3 m) against a contrasting background. The sampler backs away from the target until the prism or optical wedge image is displaced as shown for the "borderline" tree in figure 14, or until the target exactly fills the sighting angle of the stick-type angle gage. The exact distance to the target from the crosspiece of the angle gage, or from the sampler's eye in the case of prisms or optical wedges, is then measured. The BAF is calculated using the following formula:

$$\text{BAF} = 10,890 \frac{W^2}{D}$$

W is the diameter (width) of the circular target in feet, and D is the distance to the target in feet. This calculated BAF is then used in all subsequent computations.

STOCKING RATE (DENSITY) SAMPLING

The Federal regulations state that areas revegetated with trees or shrubs will have a minimum stocking rate of 450 trees or shrubs per acre (1 125/ha). Areas developed for fish and wildlife management and permit areas of 40 acres (16 ha) or less have slightly different requirements. Refer to the regulations from the Federal Register in appendix I for the specific requirements for these situations.

Density, or stocking rate, means the number of individual trees or shrubs per unit area. Several sampling methods are available for estimating the density of trees and shrubs. Methods that are accurate and applicable to sampling revegetated areas are the Bitterlich variable radius method for trees and the density quadrat method for shrubs.

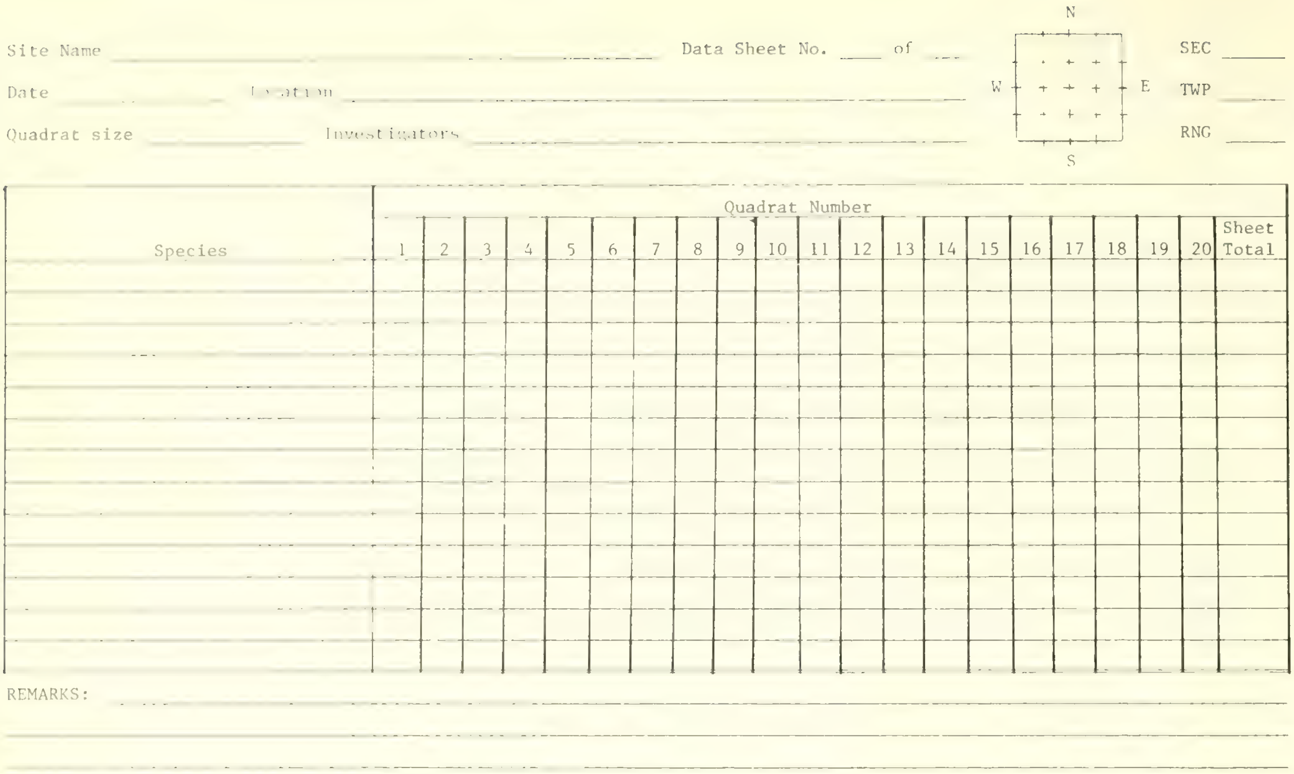
Bitterlich's Variable Radius Method for Trees

The Bitterlich's variable radius method is a reliable technique for estimating tree density. The procedures for this method were given under the section on cover methodology and should be used to obtain tree density or stocking rate.

Density Quadrat Method for Shrubs and Trees

Samples should be located within the sampling unit by using one of the schemes outlined in the section on random sampling schemes. An example data form is presented in figure 16. The specific methodology is as follows:

1. The sample quadrat is randomly placed within the sampling unit. Square and rectangular quadrats can be established with the use of tape measures. The quadrat should be oriented in a consistent direction from the initial sampling point for all samples taken. Circular quadrats can be established surrounding the sampling point by positioning one end of a rope of fixed radius over the sampling point and rotating the other end of the rope around the point in a complete circle. All shrubs or trees within the quadrat are counted while the rope is being rotated.
2. All shrubs or trees within the quadrat are counted and recorded by species (see fig. 16). Shrubs or trees rooted within the quadrat are counted; those rooted outside of the quadrat are not included in the sample.
3. Individual quadrat values summarized by species are used for statistical analysis.



Site Name ______________ Data Sheet No. ____ of ____ SEC ______

Date ______ Location ______________ TWP ______

Quadrat size ______ Investigators ______________ RNG ______

Species	Quadrat Number																				Sheet Total
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	

REMARKS: ______________

Figure 16.—Data form for the density quadrat method.

4. A method for determining sample size is given in the section on statistics. The probability level used should be 0.10.

Additional considerations for this method are as follows:

1. **Quadrat size** should be based upon the size and the spacing of the individual shrubs or trees. A quadrat size containing an average of four individuals is often recommended; however, any number of individuals can be contained within the quadrat if accurate counts can be made. Square quadrats of 13.2 × 13.2 ft (4 × 4 m) are commonly used for shrub species up to 9.9 ft (3 m) height. Circular quadrats with radius of 11.7 ft (1/100 acre) (3.566 m [0.004 ha]) or 8.3 ft (1/200 acre) (2.529 m [0.002 ha]) are also frequently used for shrubs. For trees, circular quadrats with radius of 16.7 ft (1/50 acre) (5.09 m [0.008 ha]) are often used.

2. **Quadrat shape** has little effect on the accuracy of density measurements in uniformly distributed vegetation. Rectangular quadrats are considered more accurate than other quadrat shapes in patterned vegetation when the long axis of the rectangular quadrat transects any banding in the vegetation pattern. Circular quadrats are probably the most efficient quadrat shape for field implementation.

3. The most efficient and reliable method of evaluating small or irregularly shaped plantings may be a direct count of all living and dead shrubs or trees. A determination of survival rate (the number of living trees or shrubs divided by the total number of trees or shrubs planted) will be sufficient for determining adequacy of revegetation. The minimum acceptable survival rate will be dependent upon the planting scheme and the management plan for the area, but should never be less than 80 percent. This method is particularly well suited to shrubs or trees that are planted in strips or rows as hedgerows or windbreaks.

DIVERSITY CONCEPTS

The concept of diversity has received numerous interpretations in the scientific literature. During recent years, however, there has been a consensus that diversity has two basic components. The first, species richness, pertains simply to the number of species within a defined area. The second, species evenness, refers to the proportionate distribution of individuals among species. These two components of diversity are often assessed together and called "heterogeneity."

Ideally, a comparison of the diversity of two areas would determine if the areas had similar species numbers and if the distribution of individuals among species was approximately the same. It should follow then that the measurement of diversity requires a list of the species in the area under investigation and a measure of each species importance or the contribution of the sum of its individuals to the community. Measures of importance are derived from estimates of numbers (density), production, or cover. (The selection of the appropriate importance measure is discussed in a following section.)

Although diversity is usually discussed in terms of species, it may also be thought of in terms of life-forms. Indeed, the use of life-forms in the comparison of the diversity of a reference area and a revegetated area may be more appropriate, especially if species different from those in the reference area are seeded in the revegetated area.

Many excellent references on the concepts of diversity are available to the interested reader. They include Mueller-Dombois and Ellenberg (1974), Peet (1974), Pielou (1975, 1974, and 1966), and Whittaker (1972 and 1965).

Several methods of comparing the diversity of two areas are available to the investigator. These can, in general, be categorized as diversity indices, rank correlation tests, and similarity indices. Similarity indices probably provide the best available method for comparing reference and revegetated areas. However, presented here is a specific example of each category chosen on the basis of its appropriateness for the comparison of reference and revegetated areas. These include Shannon's diversity index, H′, Spearman's rank correlation coefficient, R_o, and Sorenson's similarity index. The basic concepts, assumptions, and limitations of each are discussed and the necessary calculations are illustrated. Table 9 shows the requirements and comparisons of all three.

Shannon's Diversity Index—H′

Indices of diversity are, perhaps, the most frequently used measure of diversity. They are often assumed to provide "absolute" measures of diversity regardless of the type of importance value or the kind of communities being investigated. However, there are certain assumptions and constraints associated with diversity indices that must be considered.

1. In general, diversity indices assume that all individuals are equal to one another. This is obviously not the case with such diverse life-forms as trees and grasses or forbs and shrubs. In addition, the desirability of a species, for example a perennial native grass versus an annual introduced forb, is not taken into account.
2. There is no mathematical way to compare values obtained from two different communities using the same diversity index. This is because a change in the index at one end of the scale is not necessarily proportionate to the same amount of change at the other end.
3. When examining two different communities, diversity indices do not always reveal changes in the apportionment of individuals among species. For example, a reference area might have species A, B, C, D, and the apportionment of individuals might be 10, 2, 2, 1, respectively. If the revegetated area had the same species, A, B, C, D, but the apportionment of individuals were reversed, 1, 2, 2, 10, the diversity indices would still be the same for both areas.
4. The timing of sampling can have a large influence on diversity indices. This is primarily due to the contribution or lack of annual species that may exhibit ephemeral characteristics.

Although diversity indices have received widespread use, their applicability in the comparison of revegetated areas to reference areas is questionable, and it is recommended that they not be used. However, because of the current popularity of diversity indices, a discussion and example of the Shannon H′ diversity index is presented.

The Shannon index, one of the most widely used diversity indices, measures heterogeneity (richness and evenness). It is based upon the assumption that the more species there are and the more even the distribution of individuals among species, the greater the diversity (Pielou 1966). The formula for an infinite population is:

$$H' = -\sum_{i=1}^{s} p_i \log p_i$$

where p_i is the percentage importance. The index, H′, is logarithmically related to the number of species. It is most sensitive to changes in the importance of the rare species in the sample (Peet 1974). For samples containing only a few species, this index may result in low dispersion and may be influenced by the quantitative relation of the dominant species. Like most indices of this type, the importance value used (density, cover, or production) will affect the value of H′.

The base of the logarithm used is immaterial. Changes in the base of the logarithms only change the units in which diversity is measured (Pielou 1974). It is necessary, however, to state the units that are used.

An example calculation for the Shannon index using logarithms of base 10 is given in table 10. The importance value used is dry weight (DW) production and the percentage of the importance value, p_i, is the percent production of each species or life-form of the total production. Because the maximum value of H′ is equal to one, the H′ values obtained here, 0.872 for the revegetated area and 0.969 for the reference area, are actually very high. If it can be assumed that the calculated H′ value accurately depicts the diversity of the reference area, then the H′ value of the revegetated area would have to be within a

Table 9.—*A comparison of Shannon's index, Spearman's R_o, and Sorenson's similarity index*

Characteristics	Shannon's index H′	Spearman's R_o	Sorenson's similarity index
Requires species or life form list	X	X	X
Requires measure of importance; production, cover, or density	X	X	X
Requires same number of species or life forms in both areas		X	
Does not require same number of species or life forms in both areas	X		X
Tests apportionment of species or life forms between areas		X	X
Does not test apportionment of species or life forms between areas	X		
Independent diversity index for each area	X		
Diversity measure derived from comparison of both areas		X	X

Table 10.—*An example calculation of the Shannon index*

Life form or species	Revegetated area			Reference area		
	lb/acre DW	p_i	$-(p_i \log p_i)$	lb/acre DW	p_i	$-(p_i \log p_i)$
1	553	0.200	0.140	524	0.177	0.133
2	479	.173	.132	348	.117	.109
3	234	.084	.090	441	.149	.123
4	625	.226	.146	563	.190	.137
5	351	.127	.114	197	.066	.078
6	26	.009	.018	151	.051	.066
7	108	.039	.055	94	.032	.048
8	84	.030	.046	175	.059	.073
9	67	.025	.039			
10	242	.087	.092			
11				269	.091	.095
12				43	.014	.026
13				123	.042	.058
14				36	.012	.023
Σ	2,769	1.000	.872	2,964	1.000	.969

certain limit of the reference area H′ in order to meet the diversity criteria. In interpreting and in calculating diversity indices, however, the following considerations must be made:

1. H′ is a relative value. The H′ for the reference area is not directly comparable to H′ for the revegetated area, nor are the individual values of $-(p_i \log p_i)$.
2. Since H′ is a relative value, the individual values of $-(p_i \log p_i)$ are not proportionate to one another and cannot be reapportioned to equal 100 percent.
3. All species or life-forms must be included in the percentage importance value. Eliminating certain species will disproportionately weight the importance of other species.

If the Shannon index is to be used in the evaluation of the diversity of reference and revegetated areas, it is important that the undesirable or weedy species not be used as a basis for comparison. They should be included in the total community value (density, cover, or production) from which the individual species importance values (a percentage of the whole) are derived, but the more desirable species in the community should be used to determine if the diversity criteria have been met.

Spearman's Rank Order Correlation Coefficient—R_0

A direct, statistical comparison between the importance values (production, cover, or density) of the species of reference and revegetated areas appears to be a logical method for assessing diversity. Spearman's R_0 is a nonparametric statistical test that provides a comparison of the apportionment of the species within the two areas. The comparison is based on the difference between the magnitude of importance (ranking) of each of the species that exist in the two areas. Spearman's rank order correlation coefficient is explained in most statistical texts, such as Sokal and Rohlf (1969), and Snedecor and Cochran (1967).

The constraints of using this test are as follows:

1. Both the reference area and the revegetated area must have the same number of species or life-forms. This test is therefore most applicable for use with life-forms.
2. The use of this test requires the assumption that all rankings are equally likely, or that the distribution of individuals among species rank order applications is perfectly even. Jumars (1980) has stated that this assumption is unreasonable for most natural communities, and may invalidate the use of rank correlation tests for the comparison of similarity among species rank orders of abundance between communities.

The test statistic for Spearman's R_0, Spearman's R_s, is defined by the expression

$$R_s = 1 - \frac{6\Sigma d_i^2}{n(n^2 - 1)}$$

where

d_i = The difference between the two ranks

n = The number of comparisons

The null hypothesis to be tested is that the importance values for the two areas are apportioned between the species or life-forms in the same manner. For a one-sided test of the null hypothesis:

$R_s \leq R_0$: accept H_0

$R_s > R_0$: reject H_0

The critical values of Spearman's rank correlation coefficient, the R_0 values, are found in table 11.

Table 11.—*Critical values of Spearman's rank correlation coefficient*

n	$\alpha = 0.10$	$\alpha = 0.05$	$\alpha = 0.02$	$\alpha = 0.01$
5	0.900	--	--	--
6	.829	0.886	0.943	--
7	.714	.786	.893	--
8	.643	.738	.833	0.881
9	.600	.683	.783	.833
10	.564	.648	.745	.794
11	.523	.623	.736	.818
12	.497	.591	.703	.780
13	.475	.566	.673	.745
14	.457	.545	.646	.716
15	.441	.525	.623	.689
16	.425	.507	.601	.666
17	.412	.490	.582	.645
18	.399	.476	.564	.625
19	.388	.462	.549	.608
20	.377	.450	.534	.591
21	.368	.438	.521	.576
22	.359	.428	.508	.562
23	.351	.418	.496	.549
24	.343	.409	.485	.537
25	.336	.400	.475	.526
26	.329	.392	.465	.515
27	.323	.385	.456	.505
28	.317	.377	.448	.496
29	.311	.370	.440	.487
30	.305	.364	.432	.478

From Olds 1938.

In addition, a t* value can be calculated to test the null hypothesis:

$$t = R_S \sqrt{(n-2)/(1-R^2s)}\cdot$$

The calculated t value is compared with t_{n-2} $(\alpha/2)$ from the t-table (refer to table 12).

$t^* \leq t_{n-2} (\alpha/2)$: accept H_o

$t^* > t_{n-2} (\alpha/2)$: reject H_o

An example of a comparison between a revegetated area and a reference area using Spearman's R_O is given in table 13. The species or life-form from each area is first ranked according to the magnitude of the importance value. The difference between the two ranks of those species or life-forms found in both areas, d_i, is then obtained by subtracting rank 1, R_1, from rank 2, R_2. The value of d_i^2 is derived by squaring each of the values of d_i. Once these values have been obtained, the test statistic for Spearman's R_O or R_S is computed:

$$R_S = 1 - \frac{6\Sigma d_i^2}{n\,(n^2 - 1)}$$

$$= 1 - \frac{6\,(56)}{12\,(12^2 - 1)}$$

$$= 1 - \frac{336}{1716}$$

$$= 0.804$$

The R_O value for n = 12 and = 0.10 is 0.497 (see table 11). Because the test statistic, $R_S = 0.804$, is greater than the critical value, $R_O = 0.497$, the null hypothesis is rejected. The revegetated area presented in this example did not meet the criteria established for successful revegetation, because the species importance values for the two areas were not apportioned in a similar manner.

If t values are tested, the analysis is

$$t^* = \sqrt{(12-2)/(1-.804^2)}$$

$$= 4.276$$

Because the value for t_{10} (0.05), 1.812, is less than the calculated t* value, 4.276, the null hypothesis is rejected.

Table 12.—*t-Distribution values for various levels of n, or degrees of freedom, d.f., for a one-sided test*

	Probability of a larger value of t, sign considered								
df	0.25	0.2	0.15	0.1	0.05	0.25	0.01	0.005	0.0005
1	1.000	1.376	1.963	3.078	6.314	12.706	31.821	63.657	636.619
2	.816	1.061	1.386	1.886	2.920	4.303	6.965	9.925	31.598
3	.765	.978	1.250	1.638	2.353	3.182	4.541	5.841	12.941
4	.741	.941	1.190	1.533	2.132	2.776	3.747	4.604	8.610
5	.727	.920	1.156	1.476	2.015	2.571	3.365	4.032	6.859
7	.711	.896	1.119	1.415	1.895	2.365	2.998	3.449	5.405
8	.706	.889	1.108	1.397	1.860	2.306	2.896	3.355	5.041
9	.703	.883	1.100	1.383	1.833	2.262	2.821	3.250	4.781
10	.700	.879	1.093	1.372	1.812	2.228	2.764	3.169	4.587
11	.697	.876	1.088	1.363	1.796	2.201	2.718	3.106	4.437
12	.695	.873	1.083	1.356	1.782	2.179	2.681	3.055	4.318
13	.694	.870	1.079	1.350	1.771	2.160	2.650	3.012	4.221
14	.692	.868	1.076	1.345	1.761	2.145	2.624	2.977	4.140
15	.691	.866	1.074	1.341	1.753	2.131	2.602	2.947	4.073
16	.690	.865	1.071	1.337	1.746	2.120	2.583	2.921	4.015
17	.689	.863	1.069	1.333	1.740	2.110	2.567	2.898	3.965
18	.688	.862	1.067	1.330	1.734	2.101	2.552	2.878	3.922
19	.688	.861	1.066	1.328	1.729	2.093	2.539	2.861	3.883
20	.687	.860	1.064	1.325	1.725	2.086	2.528	2.845	3.850
21	.686	.859	1.063	1.323	1.721	2.080	2.518	2.831	3.819
22	.686	.858	1.061	1.321	1.717	2.074	2.508	2.819	3.792
23	.685	.858	1.060	1.319	1.714	2.069	2.500	2.807	3.767
24	.685	.857	1.059	1.318	1.711	2.064	2.492	2.797	3.745
25	.684	.856	1.058	1.316	1.708	2.060	2.485	2.787	3.725
26	.684	.856	1.058	1.315	1.706	2.056	2.479	2.779	3.707
27	.684	.855	1.057	1.314	1.703	2.052	2.473	2.771	3.690
28	.683	.855	1.056	1.313	1.701	2.048	2.467	2.763	3.674
29	.683	.854	1.055	1.311	1.699	2.045	2.462	2.756	3.659
30	.683	.854	1.055	1.310	1.697	2.042	2.457	2.750	3.646
40	.681	.851	1.050	1.303	1.684	2.021	2.423	2.704	3.551
60	.679	.848	1.046	1.296	1.671	2.000	2.390	2.660	3.460
120	.677	.845	1.041	1.289	1.658	1.980	2.358	2.617	3.373
∞	.674	.842	1.036	1.282	1.645	1.960	2.326	2.576	3.291

Table 13.—*An example of ranked revegetated and reference areas, the difference between the two, and the difference squared*

Life-form or species	Revegetated area lb/acre DW	R_1	Reference area lb/acre DW	R_2	d_i	d_i^2
1	653	2	624	2	0	0
2	579	3	448	4	-1	1
3	334	5	591	3	2	4
4	725	1	663	1	0	0
5	451	4	297	6	-2	4
6	26	11	151	8	3	9
7	108	8	94	10	-2	4
8	342	6	225	7	-1	1
9	67	10	409	5	5	25
10	84	9	43	11	-2	4
11	131	7	123	9	-2	4
12	19	12	36	12	0	0
					$\Sigma =$	56

Similarity Indices

Indices of similarity provide a means of mathematically comparing two different plant communities. They are, in general, a function of the number of plant species or life-forms found in both communities as well as the number found in only one community or the other. In addition, certain indices of similarity (IS) incorporate the importance value of each species or life-form present in the community. Both species or life-form number and the distribution of individuals within each area are included in these indices. Similarity indices are simple and direct methods of comparing two communities, and in most cases, provide more appropriate comparisons of the diversity of reference and revegetated areas than either Shannon's diversity index or Spearman's rank correlation coefficent.

Three separate indices will be presented here. Two of the indices, Motyka and others' (1950) version of Sorensen's similarity index and Bray and Curtis' (1957) version of Sorensen's similarity index, are closely related. Bray and Curtis' version of Sorensen's similarity index is merely a computational simplification of Motyka and others' version that requires the use of percent values for each species or life form. These two versions of Sorensen's similarity index produce identical results. The general form of these indices has been endorsed by Steward (1982) for comparing the diversity of revegetated and reference areas. The third index to be included is Spatz' (1970) modification of Jaccard's index. It has been suggested by Dr. Ed DePuit (personal communication) that Spatz' index provides a more reliable comparison of reference and revegetated communities than the modifications of Sorensen's index. The formula for each of the indices and examples of their use are provided.

Motyka's version of Sorensen's similarity index (IS_{MO}) is:

$$IS_{MO} = \frac{2\ MW}{MA + MB}$$

where

MW = Sum of the smaller importance values of the species or life-forms common to both areas

MA = The sum of the importance values of all species or life-forms in one area

MB = The sum of the importance values of all species or life-forms in the other area

The value of the index ranges from 0 to 1, with 1 being complete similarity.

Bray and Curtis' version of Sorensen's similarity index is as follows:

$$IS_{BC} = \frac{2\ MW}{200} \times 100 \quad \text{or} \quad IS_{BC} = MW(\text{percent})$$

where

MW = Sum of the smaller importance values of the species or life-forms common to both areas.

This index, as noted earlier, produces identical results to Motyka and others' version of Sorensen's similarity index. Percent values are used instead of importance values. Any differences between the indices are the result of rounding.

Spatz' modification of Jaccard's index is calculated as follows:

$$IS_{SP} = R \times \frac{MC}{MA + MB + MC} \times 100$$

where

R = The smaller values of the species or life-forms common to both areas are first divided by the greater values. These fractions are then added up and the sum is divided by the total number of species in both areas

MC = The sum of the values of all species or life-forms common to both areas

MA = The sum of the values of all species or life-forms in one area

MB = The sum of the values of all species or life-forms in the second area

This index consists of two separate parts. The first part (R) expresses the relative similarity of the two areas being compared, in terms of the number of common species and the differences in importance values between individual species. The second part is the quantitative application of Jaccard's index. It examines the relative similarity of the two areas in terms of importance values.

Tables 14, 15, and 16 are examples of the calculation of the 3 different similarity indices using both species and life-form data. The importance values used are production values (lb/acre dry weight). Table 14 shows the common and unique pecies of a revegetated area and a reference area and an example calculation of Motyka and others' version of Sorensen's ndex. Two examples using life-forms are shown in tables 15 nd 16; these illustrate the effect of differences in importance values on the 3 similarity indices. Table 16 uses the same life-forms but a different apportionment of importance values.

The following considerations should be made when interpreting similarity indices:

1. The greater the difference in magnitude between the two mportance values and the fewer the species or life-forms in ommon, the smaller the index of similarity.

2. A similarity index value of 0.80 normally indicates a high degree of similarity between two areas. The index value chosen s the lower limit for meeting the diversity criteria for the evegetated area will be dependent upon the vegetation type nd the management plan for the area. One method of determining a realistic index of similarity is to sample replicate areas within the reference area and to calculate the similarity index or the replicates. This index would be a measure of the inerent similarity within the reference. A value slightly lower han the one obtained for the reference could serve as the tandard of comparison for the similarity between the reference rea and the revegetated area.

Table 14.—*An example of the common and unique species of a revegetated and reference area and the calculation of Motyka's version of Sorensen's index*

Species	Revegetated area (MA) lb/acre DW	Common species (MA) lb/acre DW	Common species (MB) lb/acre DW	Reference area (MB) lb/acre DW
1		553	524	
2		479	348	
3		234	441	
4		625	563	
5		351	197	
6		26	151	
7		108	94	
8		84	175	
9	67			
10	242			
11				269
12				43
13				123
14				36
Total	309			471

Calculation of Motyka and others' version of Sorensen's index.

$$IS_{MO} = \frac{2\ MW}{MA + MB}$$

$$\begin{aligned} MW &= 524 + 348 + 234 + 563 + 197 + 26 + 94 + 84 \\ &= 2{,}070 \\ MA &= 553 + 479 + 234 + 625 + 351 + 26 + 108 + 84 + 67 \\ &\quad + 242 \\ &= 2{,}769 \\ MB &= 524 + 348 + 441 + 563 + 197 + 151 + 94 + 175 + \\ &\quad 269 + 43 + 123 + 36 \\ &= 2{,}964 \end{aligned}$$

$$IS_{MO} = \frac{2(2{,}070)}{2{,}769 + 2{,}964} = 0.72 \times 100 = 72\%$$

Table 15.—*Example of high similarity between a revegetated area and a reference area as compared by 3 similarity indices.*

Life-form		Revegetated area lb/acre DW	Percent comp.	Reference area lb/acre DW	Percent comp.
I.A	Annual grass	187	15	28	2
I.B.2.b.	Perennial cool season bunchgrass	361	29	503	36
I.B.2.a.	Perennial warm season bunchgrass	274	22	391	28
I.B.1.a.	Perennial warm season rhizomatous grass	162	13	154	11
II.A.	Annual herbs	199	16	14	1
II.B.	Perennial herbs	62	5	196	14
II.C.	Biennial herbs			28	2
III.A.1.	Broadleaf deciduous shrubs			84	6
Total		1,245	100	1,398	100

Motyka and others' version of Sorensen's index:

$$IS_{MO} = \frac{2\ MW}{MA + MB} \times 100$$

$$MW = 28 + 361 + 274 + 154 + 14 + 62 = 893$$

$$MA = 187 + 361 + 274 + 162 + 199 + 62 = 1{,}245$$

$$MB = 28 + 503 + 391 + 154 + 14 + 196 + 28 + 84 = 1{,}398$$

$$IS_{MO} = \frac{2(893)}{1{,}245 + 1{,}398} = 0.677 \times 100 = 68\%$$

Bray and Curtis' version of Sorensen's index:

$$IS_{BC} = MW(\text{percent})$$

$$MW = 2 + 29 + 22 + 11 + 1 + 5 = 70$$

$$IS_{BC} = 70(\text{percent}) = 70\%$$

Spatz' version of Jaccard's index:

$$IS_{SP} = R \times \frac{MC}{MA + MB + MC} \qquad IS_{SP} = 0.37 \times \frac{192}{200} \times 100 = 36\%$$

$$R = \frac{2 \div 15 + 29 \div 36 + 22 \div 28 + 11 \div 13 + 1 \div 16 + 5 \div 14}{8}$$

$$= \frac{0.13 + 0.80 + 0.79 + 0.85 + 0.06 + 0.36}{8} = 0.37$$

Table 16.—*Example of low similarity between a revegetated area and a reference area as compared by 3 similarity indices.*

Life-form		Revegetated area lb/acre DW	Percent comp.	Reference area lb/acre DW	Percent comp.
.A	Annual grass	373	25	28	2
.B.2.b.	Perennial cool season bunchgrass			483	37
.B.2.a.	Perennial warm season bunchgrass	194	13	345	26
.B.1.a.	Perennial warm season rhizomatous grass	448	30	148	11
I.A.	Annual herbs	433	29	13	1
I.B.	Perennial herbs	45	3	27	2
I.C.	Biennial herbs			27	2
II.A.1.	Broadleaf deciduous shrubs			80	6
Total		1,493	100	1,312	99

Motyka and others' version of Sorensen's index:

$$IS_{MO} = \frac{2\ MW}{MA + MB} \times 100$$

$$MW = 28 + 194 + 148 + 13 + 45 = 428$$

$$MA = 373 + 194 + 448 + 433 + 45 = 1{,}493$$

$$MB = 28 + 483 + 345 + 148 + 13 + 188 + 27 + 80 = 1{,}312$$

$$IS_{MO} = \frac{2(428)}{1{,}493 + 1{,}312} = 0.305 \times 100 = 30\%$$

Bray and Curtis' version of Sorensen's index:

$$IS_{BC} = MW(\text{percent})$$

$$MW = 2 + 13 + 11 + 1 + 13 = 30$$

$$IS_{BC} = 30(\text{percent}) = 30\%$$

Spatz' version of Jaccard's index:

$$IS_{SP} = R \times \frac{MC}{MA + MB + MC} \qquad IS_{SP} = 0.15 \times \frac{155}{200} \times 100 = 12\%$$

$$R = \frac{2 \div 25 + 13 \div 26 + 11 \div 30 + 1 \div 29 + 3 \div 14}{8}$$

$$= \frac{0.08 + 0.5 + 0.37 + 0.03 + 0.21}{8} = 0.15$$

Choice of a Similarity Index

The two types of indices, Spatz' index and Sorensen's modifications, place different amounts of emphasis on the quantitative and qualitative properties of revegetated and reference areas. In general, Spatz' index combines both quantitative and qualitative properties while Sorensen's modifications are more strictly quantitative (Mueller-Dombois and Ellenberg 1974). For example, Spatz' index places a greater emphasis on the comparison of the number of common and different species or life-forms and the differences in importance values between individual species or life forms. Comparisons of revegetated and reference areas with several common species or life-forms in which all of the common species or life-forms have large importance values generally produce high similarity values when modifications of Sorensen's index are used. However, if the same areas also have species or life-forms with smaller importance values that occur in only one or the other of the areas, Spatz' index will produce a much smaller similarity value than Sorensen's modifications (see tables 15 and 16).

Choice of an index will ultimately depend upon the objectives of the investigator. In most cases Spatz' index will provide a more rigorous comparison of two areas.

Selection of Importance Values

The selection of importance values for use with the Spearman's R_0 diversity indices, or similarity indices deserves careful consideration. Productivity is normally the best measure of a species' importance; it indicates both the species' biological activity and the amount of the communities' resources that a species utilizes. The measure has little ambiguity due to collection methods and is directly comparable between species. Density, however, is an inappropriate measure in many communities because of the huge differences in the contribution of individuals of different life-forms (say, trees versus herbs) to the second area.

MEETING STATISTICAL REQUIREMENTS

The federal regulations state that "the ground cover and productivity of the revegetated area shall be considered equal if they are at least 90 percent of the ground cover and productivity of the reference area with 90 percent statistical confidence or with 80 percent statistical confidence on shrublands" (CFS 816–116). In addition, the regulations require that certain areas, depending upon the proposed management, will be stocked with a specified number of trees or shrubs. (Refer to the Rules and Regulations, appendix I). To meet the regulation requirements, it will be necessary to: (1) calculate the number of sample observations required to achieve the specified level of confidence for each production, cover, and density sample; and (2) determine if the revegetated area has 90 percent or more of the production and cover of the reference area from a statistical confidence limit estimate. Depending upon the needs of the investigator, sample data can be summarized as: (1) total production, cover, or density in each quadrat regardless of species or life form; or (2) production, cover, or density of each species or life form within each quadrat.

The hypothesis to be examined is H_O: $(\mu_2 - .9\mu_1) \geq 0$ vs. H_A: $(\mu_2 - .9\mu_1) < 0$, where μ_2 equals the mean production, cover, or density of the revegetated area and μ_1 equals the mean production, cover, or density of the reference area. This says that the revegetated area is successfully revegetated when its mean production, cover, and density is 90 percent or greater than that of the reference area.

Required Sample Size

A two-stage procedure is used in which the final required sample size is calculated from a first stage sample drawn from both the reference and revegetated sample areas (Booth, personal communication).[1] The minimum sample size required in the first stage is calculated from an estimate of the mean and variance of the production or cover on the reference area.

GENERAL NOTATION:

n_{ij} = The size of the sample from population i (i = 1; reference area and i = 2; revegetated area), in stage j (j = 1; first stage and j = 2; second stage)

t = A t-value from the table of the t distribution (table 20)

d = The closeness with which we wish to estimate the difference of interest

$\bar{x}_i$ = Estimate of the mean from population i

s_i^2 = Estimate of the variance from population i

STEP 1. Obtain an estimate of the mean and variance of the production or cover of the reference area. This estimate can be derived from a presample or from past sampling experience. Production values should be calculated as dry weights.

Select a value for d. This value is the size of the difference we wish to detect. Ideally, this value is a predetermined standard (for example x number of pounds) that is totally independent of the mean and is chosen by the sampler on the basis of what is both acceptable and realistic.

Because of the variety of vegetation types being sampled and the large difference in production values obtained, it is unlikely that the sampler will always know what a realistic value of d is. As a rule, we suggest that d be computed as a small percentage of the mean of the reference area. For example, this value could be one-fourth, or one-half, of 1 percent of the mean of the reference area. If the revegetated area had a mean production of 90 percent of that of the reference area, the difference between the two means would be 10 percent of the mean of the reference area. This difference is the quantity of interest; 5 percent of this difference would be one-half of 1 percent of the mean of the reference area. This is the rationale for using one-fourth or one-half of 1 percent of the reference mean for d. In areas in which production values are low and variances are high, such as deserts, this method may result in the selection of a d value that is unrealistically small. Experience in the sampling of different vegetation types should aid the investigator in selecting realistic d values.

The relationship of d and the variance (s^{*2}, initial estimate or guess of the variance of the reference area) to sample size (n) is shown in tables 17 and 18. As d decreases, sample size increases, and as the variance increases, sample size increases. The values presented in tables 17 and 18 are to be used only as a guide for the selection of d and n. A caution: too small a sample size in the first stage will result in a large sample size in the second stage.

Table 17.—*Values of d for selected variances and sample sizes*

Sample size	Variance																		
	100	200	300	400	500	600	700	800	900	1,000	2,000	3,000	4,000	5,000	6,000	7,000	8,000	9,000	10,000
10	6.97	9.86	12.07	13.94	15.59	17.08	18.44	19.72	20.91	22.05	31.18	38.18	44.09	49.30	54.00	58.33	62.35	66.14	69.71
20	4.93	6.97	8.54	9.86	11.02	12.07	13.04	13.94	14.79	15.59	22.05	27.00	31.18	34.86	38.18	41.24	44.09	46.77	49.30
30	4.02	5.69	6.97	8.05	9.00	9.86	10.65	11.38	12.07	12.73	18.00	22.05	25.46	28.46	31.18	33.67	36.00	38.18	40.25
40	3.49	4.93	6.04	6.97	7.79	8.54	9.22	9.86	10.46	11.02	15.59	19.09	22.05	24.65	27.00	29.16	31.18	33.07	34.86
50	3.12	4.41	5.40	6.24	6.97	7.64	8.25	8.82	9.35	9.86	13.94	17.08	19.72	22.05	24.15	26.08	27.89	29.58	31.18
60	2.85	4.02	4.93	5.69	6.36	6.97	7.53	8.05	8.54	9.00	12.73	15.59	18.00	20.12	22.05	23.81	25.46	27.00	28.46
80	2.46	3.49	4.27	4.93	5.51	6.04	6.52	6.97	7.39	7.79	11.02	13.50	15.59	17.43	19.09	20.62	22.05	23.38	24.65
100	2.20	3.12	3.82	4.41	4.93	5.40	5.83	6.24	6.61	6.97	9.86	12.07	13.94	15.59	17.08	18.44	19.72	20.91	22.05
150	1.80	2.55	3.12	3.60	4.02	4.41	4.76	5.09	5.40	5.69	8.05	9.86	11.38	12.73	13.94	15.06	16.10	17.08	18.00
200	1.56	2.20	2.70	3.12	3.49	3.82	4.12	4.41	4.68	4.93	6.92	8.54	9.86	11.02	12.07	13.04	13.94	14.79	15.59
250	1.39	1.97	2.41	2.79	3.12	3.42	3.69	3.94	4.18	4.41	6.24	7.64	8.82	9.86	10.80	11.67	12.42	13.23	13.94
500	.99	1.39	1.71	1.97	2.20	2.41	2.61	2.79	2.96	3.12	4.41	5.40	6.24	6.97	7.64	8.25	8.82	9.35	9.86
1,000	.70	.99	1.21	1.39	1.56	1.71	1.84	1.97	2.09	2.20	3.12	3.82	4.41	4.93	5.40	5.83	6.24	6.61	6.97
3,000	.40	.57	.70	.80	.90	.99	1.06	1.14	1.21	1.27	1.80	2.20	2.55	2.85	3.12	3.37	3.60	3.82	4.02
5,000	.31	.44	.54	.62	.70	.76	.82	.88	.94	.99	1.39	1.71	1.97	2.20	2.41	2.61	2.79	2.96	3.12
10,000	.22	.31	.38	.44	.49	.54	.58	.62	.66	.70	.99	1.21	1.39	1.56	1.71	1.84	1.97	2.09	2.20
20,000	.16	.22	.27	.31	.35	.38	.41	.44	.47	.49	.70	.85	.99	1.10	1.21	1.30	1.39	1.48	1.56
30,000	.13	.18	.22	.25	.28	.31	.34	.36	.38	.40	.57	.70	.80	.90	.99	1.06	1.14	1.21	1.27
50,000	.10	.14	.17	.20	.22	.24	.26	.28	.30	.31	.44	.54	.62	.70	.76	.82	.88	.94	.99

---

[1] Note: to adapt this procedure to changes in the regulations see Appendix VII.

able 18.—*Sample sizes for selected variances and d values*

	Variance																	
d	100	200	300	400	500	600	700	800	900	1,000	2,000	3,000	4,000	5,000	6,000	7,000	8,000	9,000	10,000
1	486	972	1,458	1,944	2,430	2,916	3,402	3,888	4,374	4,860	9,720	14,580	19,440	24,300	29,160	34,020	38,880	43,740	48,600
2	122	243	365	486	608	729	851	972	1,094	1,215	2,430	3,645	4,860	6,075	7,290	8,505	9,720	10,935	12,150
3	54	108	162	216	270	324	378	432	486	540	1,080	1,620	2,160	2,700	3,240	3,780	4,320	4,860	5,400
4	30	61	91	122	152	182	213	243	273	304	608	911	1,215	1,519	1,823	2,126	2,430	2,734	3,038
5	19	39	58	78	97	117	136	156	175	194	389	538	778	972	1,166	1,361	1,555	1,750	1,944
6	14	27	41	54	68	81	95	108	122	135	270	405	540	675	810	945	1,080	1,215	1,350
7	10	20	30	40	50	60	69	79	89	99	198	298	397	496	595	694	793	893	992
8	8	15	23	30	38	46	53	61	68	76	152	228	304	380	456	532	608	683	759
9	6	12	18	24	30	36	42	48	54	60	120	180	240	300	360	420	480	540	600
10	5	10	15	19	24	29	34	39	44	49	97	146	194	243	292	340	389	437	486
15	2	4	6	9	11	13	15	17	19	22	43	65	86	108	130	151	173	194	216
20	1	2	4	5	6	7	9	10	11	12	24	36	49	61	73	85	97	109	122
25	1	2	2	3	4	5	5	6	7	8	16	23	31	39	47	54	62	70	78
30	1	1	2	2	3	3	4	4	5	5	11	16	22	27	32	38	43	49	54
35	0	1	1	2	2	2	3	3	4	4	8	12	16	20	24	28	32	36	40
40	0	1	1	1	2	2	2	2	3	3	6	9	12	15	18	21	24	27	30
45	0	0	1	1	1	1	2	2	2	2	5	7	10	12	14	17	19	22	24
50	0	0	1	1	1	1	1	2	2	2	4	6	8	10	12	14	16	17	19
60	0	0	0	1	1	1	1	1	1	1	3	4	5	7	8	9	11	12	14
70	0	0	0	0	0	1	1	1	1	1	2	3	4	5	6	7	8	9	10
80	0	0	0	0	0	0	1	1	1	1	2	2	3	4	5	5	6	7	8
90	0	0	0	0	0	0	0	0	1	1	1	2	2	3	4	4	5	5	6
00	0	0	0	0	0	0	0	0	0	0	1	1	2	2	3	3	4	4	5

STEP 2. Compute the **minimum** required sample size from he reference area as

$$n_{11} = (.81)t^2s^{*2}/d^2 \qquad \text{(eq. 1)}$$

A value of 2.0 can be used for t in the initial estimate of ample size, unless s^{*2} was derived from an actual sample. The value should have (n–1) degrees of freedom and a probability f 0.1, where n is the actual sample size. The sample taken hould be about 1.5 to 2 times this value for the first stage. Jnless there is good reason to do otherwise, this would also be reasonable value for the first stage samples size from the evegetated area. If too few first stage samples are taken, the nvestigator may be required to take more second stage samples han necessary from the revegetated area.

STEP 3. Obtain the random first stage samples from the eference and revegetated areas. Compute:

$\bar{x}_{11}$ and s_1^2 from the reference area

$\bar{x}_{21}$ and s_2^2 from the revegetated area

$$s^2 = [(n_{11} - 1)s_1^2 + (n_{21} - 1)s_2^2]/(n_{11} + n_{21} - 2) \qquad \text{(eq. 2)}$$

= pooled variance from the reference and revegetated areas.

n example calculation of $\bar{x}$, and s_1^2 is given in table 19.

Table 19.—*Sample calculation of the mean, $\bar{x}$, and variance, s^2, for a hypothetical reference area*

	Reference area	
Quadrat number	x(gms dry wt)	x^2
1	82	6,724
2	94	8,836
3	88	7,744
4	116	13,456
5	88	7,744
6	120	14,400
7	104	10,816
8	85	7,225
9	102	14,400
10	92	8,464
11	106	11,236
12	94	8,836
sum(Σ)	1,189	119,881

$$\bar{x} = \frac{\text{sum of x}}{\text{total number quadrats}} = \frac{1189}{12} = 99.08$$

$$s^2 = \frac{\Sigma x^2 - \frac{(\Sigma x)^2}{n}}{n-1} = \frac{119,881 - \frac{(1189)^2}{12}}{11} = 188.26$$

STEP 4. Determine the required sample size from the revegetated area for the second stage sample. Find a value with a one-tailed t distribution that has $(n_{11} + n_{21} - 2)$ degrees of freedom and a probability of 0.1 (table 20).

Compute:

$$A = n_{11}t^2s^2 \qquad \text{(eq. 3)}$$

$$B = n_{11}d^2 - (.81)t^2s^2 \qquad \text{(eq. 4)}$$

$$n_{22} = A/B - n_{21} \qquad \text{(eq. 5)}$$

STEP 5.

A. If n_{22} is negative, no further samples are required. Go to the revegetated and reference area comparison.

B. If n_{22} is a reasonable sample size for the revegetated area, then an additional sample of that size should be obtained from the revegetated area for the second stage. A second stage sample from the reference area is not needed. After the second sample has been taken, go to the revegetated and reference area comparison.

C. If n_{22} is unreasonably large, then further sampling from both the revegetated and the reference areas will be required. A sample size of n_{22} will be selected for both the reference and revegetated areas and will be calculated as:

$$n_2 = [1.81\ t^2s^2]/d^2 - n_1 \qquad \text{(eq. 6}$$

It is assumed that the first-stage sample size was the same for both the reference and revegetated areas, namely $n_{11} = n_{21} = n_1$. The value of t has $(n_{11} + n_{21} - 2)$ degrees of freedom and a probability of 0.1, s^2 = the pooled variance calculated from equation 2, and d = the value selected in STEP 1.

Consider $n_{12} = n_{22} = n_2$, collect a sample of size n_2 from both the reference and revegetated areas, and go to the revegetated and reference area comparison.

Table 20.—*Values with a one-tailed t- distribution for various levels of n, or degrees of freedom, d.f.*

df	0.2	0.15	0.1	0.05	0.25
1	1.376	1.963	3.078	6.314	12.706
2	1.061	1.386	1.886	2.920	4.303
3	.978	1.250	1.638	2.353	3.182
4	.941	1.190	1.533	2.132	2.776
5	.920	1.156	1.476	2.015	2.571
6	.906	1.134	1.440	1.943	2.447
7	.896	1.119	1.415	1.895	2.365
8	.889	1.108	1.397	1.860	2.306
9	.883	1.100	1.383	1.833	2.262
10	.879	1.093	1.372	1.812	2.228
11	.876	1.088	1.363	1.796	2.201
12	.873	1.083	1.356	1.782	2.179
13	.870	1.079	1.350	1.771	2.160
14	.868	1.076	1.345	1.761	2.145
15	.866	1.074	1.341	1.753	2.131
16	.865	1.071	1.337	1.746	2.120
17	.863	1.069	1.333	1.740	2.110
18	.862	1.067	1.330	1.734	2.101
19	.861	1.066	1.328	1.729	2.093
20	.860	1.064	1.325	1.725	2.086
21	.859	1.063	1.323	1.721	2.080
22	.858	1.061	1.321	1.717	2.074
23	.858	1.060	1.319	1.714	2.069
24	.857	1.059	1.318	1.711	2.064
25	.856	1.058	1.316	1.708	2.060
26	.856	1.058	1.315	1.706	2.056
27	.855	1.057	1.314	1.703	2.052
28	.855	1.056	1.313	1.701	2.048
29	.854	1.055	1.311	1.699	2.045
30	.854	1.055	1.310	1.697	2.042
40	.851	1.050	1.303	1.684	2.021
60	.848	1.046	1.296	1.671	2.000
120	.845	1.041	1.289	1.658	1.980
∞	.842	1.036	1.282	1.645	1.960

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Revegetated and Reference Area Comparison

The reference area and revegetated area comparison will be based upon a lower confidence limit for $(\mu_2 - .9\mu_1)$. This analysis is similar to a test of hypothesis (such as a t-test) in hat it tells the investigator if the cover and production of the revegetated area is 90 percent of the reference area with the specified level of confidence. In addition, it allows the investigator to determine how many units (lbs/acre or kg/ha) the revegetated area deviates from the required 90 percent of the production or cover of the reference area with the specified evel of confidence.

STEP 6. Compute the weighted mean for all of the samples aken. If first and second stage samples were taken in both the revegetated and reference areas:

$$\bar{x}_{..} = w_1\bar{x}_{11} + w_2\bar{x}_{21} + w_3\bar{x}_{12} + w_4\bar{x}_{22} \qquad \text{(eq. 7)}$$

where

$w_1 = (-.9)n_{11}/n_{1.}$

$w_2 = n_{21}/n_{2.}$

$w_3 = (-.9)n_{12}/n_{1.}$

$w_4 = n_{22}/n_{2.}$

$n_{1.} = n_{11} + n_{12}$

$n_{2.} = n_{21} + n_{22}$

f the sample size requirement was met in the first stage ample:

$$\bar{x}_{..} = -.9\bar{x}_{11} + (1)\bar{x}_{21} \qquad \text{(eq. 8)}$$

f second stage samples were taken in only the revegetated areas:

$$\bar{x}_{..} = w_1\bar{x}_{11} + w_2\bar{x}_{21} + w_4\bar{x}_{22} \qquad \text{(eq. 9)}$$

STEP 7. The confidence limit is calculated using:

$$\bar{x}_{..} \pm t\,C \qquad \text{(eq. 10)}$$

where

t = a value from the t table (table 20) with $n_{11} + n_{21} - 2$ degrees of freedom and a probability of 0.1.

$C = \sqrt{(.81/n_{1.} + 1/n_{2.})s^2}$

s^2 = the pooled variance from the first stage results (eq. 2).

STEP 8. The interpretation of the confidence interval stimate is as follows:

Lower limit	**Conclusion**
positive	$\mu_2 > .9\mu_1$
negative	$\mu_2 < .9\mu_1$

f the value of the confidence limit is positive, the revegetated rea has met the requirement specified in the regulations. If the onfidence limit is negative, the revegetated area has not met he requirement.

Example 1

STEP 1. Suppose we estimate from past sampling experience hat the reference area has a mean of 3,600 lb/acre and a ariance of 1960. A d value is chosen as a small fraction, one-half, of 1 percent of this reference area mean. This value is 6 ÷ 2 = 18.

STEP 2. Compute the **minimum** required sample size from he reference area using equation 1:

$n_{11} = (.81)(2.0^2)(1960)/18^2$

$= 6350.4/324$

$= 19.6$

where t is estimated as 2.0.

Multiply the value of n_{11} obtained above by 1.5 or 2 to obtain he number of first stage random samples. In this case, 30 to 40 samples would be taken from both the reference and revegetated areas.

STEP 3. For 40 samples from both areas, we compute the following values. Calculation of $\bar{x}$ and s_1^2 is illustrated in table 19.

Calculate s^2 from equation 2.

$\bar{x}_{11} = 3322$ lb/acre $\qquad s_1^2 = 1915$

$\bar{x}_{21} = 3018$ lb/acre $\qquad s_2^2 = 2250$

$s^2 = [(40-1)1915 + (40-1)2250]/(40+40-2)$

$= 162435/78$

$= 2082.5$

STEP 4. Look up t with (40 + 40 − 2) degrees of freedom and a probability of 0.1 (table 20). Compute using equations 3, 4, and 5:

$A = (40)(1.29^2)(2082.5)$

$= 138619.5$

$B = 40(18^2) - (.81)(1.29^2)(2082.5)$

$= 10153.0$

$n_{22} = \dfrac{138619.5}{10153.0} - 40$

$= -26.3$

STEP 5. Interpretation: Since n_{22} is negative, no further samples are needed.

STEP 6. Compute the weighted mean using equation 8.

$\bar{x}_{..} = (-.9)(3322) + (1)3081$

$= 91.2$

STEP 7. Calculate the confidence limit using equation 10.

$\bar{x}_{..} - (1.29)(9.7)$

$\bar{x}_{..} - 12.5$

where

t = 1.29 for (40 + 40 − 2) degrees of freedom and a probability of 0.1

$C = \sqrt{(.81/40 + 1/40)2082.5}$

$= 9.7$

The confidence limit is

91.2 − 12.5 = 78.7

STEP 8. Interpretation: Since the limit is positive, we conclude that the mean value of the revegetated area was more than 90 percent of the mean value of the reference area. The revegetated area has met the requirement for successful revegetation, but more information is available. The revegetated area yields at least 79 lb/acre more than the critical 90 percent of the reference area yield (90 percent confidence).

Example 2

STEP 1. We estimate that the reference area has a mean of 2,200 lb/acre and a variance of 500. A value for d is chosen as one-half of 1 percent of the reference area mean. The d value is 22 ÷ 2 = 11.

STEP 2. Compute the **minimum** required sample size from the reference area using equation 1.

$n_{11} = (.81)(2.0^2)(500)/11^2$

$= 13.4$

where a t value of 2.0 is used.

The value of n_{11} is multiplied by 1.5 or 2 to obtain the number of first stage random samples. The number of samples to be taken from both the reference and revegetated areas is 20 to 27.

STEP 3. Obtain 27 samples from both areas and compute the following values. Calculation of $\bar{x}$ and s_1^2 is illustrated in table 19.

Calculate s^2 from equation 2.

$$
\begin{aligned}
x_{11} &= 2243 \text{ lb/acre} \qquad s_1^2 = 1630\\
x_{21} &= 2031 \text{ lb/acre} \qquad s_2^2 = 2462\\
s^2 &= [(27-1)1630 + (27-1)2462]/27+27-2)\\
&= 106392/52\\
&= 2046
\end{aligned}
$$

STEP 4. Look up t with $(27+27-2)$ degrees of freedom and a probability of 0.1. Compute using equations 3, 4, and 5:

$$
\begin{aligned}
A &= 27(1.30^2)(2046)\\
&= 93359.0\\
B &= 27(11^2) - (.81)(1.30^2)(2046)\\
&= 3267 - 2800.8\\
&= 466.2\\
n_{22} &= \frac{93359.0}{466.2} - 27\\
&= 173.3
\end{aligned}
$$

STEP 5. We judge n_{22} to be unreasonably large. Additional samples are required from both the reference and revegetated areas. A sample size of n_2 is taken from each of the reference and revegetated areas, where n_2 is calculated from equation 6:

$$
\begin{aligned}
n_2 &= [1.81(1.30^2)(2046)]/(11^2) - 27\\
&= 51.7 - 27\\
&= 25
\end{aligned}
$$

Consider $n_{12} = n_{22} = n_2$

STEP 6. Compute the means of the reference and the revegetated area obtained from the second stage sample, n_2.

$\bar{x}_{12} = 2197 \qquad \bar{x}_{22} = 1990$

Then compute the weighted mean for all sample means from both stages from equation 7.

$$
\begin{aligned}
\bar{x}.. &= (-.47)2243 + (.52)2031 + (-.43)2197 + (.48)1990\\
&= -1054.2 + 1056.1 - 944.7 + 955.2\\
&= 12.4
\end{aligned}
$$

where

$$
\begin{aligned}
w_1 &= (-.9)27/52 = -.47\\
w_2 &= 27/52 = .52\\
W_3 &= (-.9)25/52 = -.43\\
w_4 &= 25/52 = .48\\
n_1. &= 27 + 25 = 52\\
n_2. &= 27 + 25 = 52
\end{aligned}
$$

STEP 7. Calculate the confidence limit from equation 10.

$$
\begin{aligned}
&\bar{x}.. - 1.30(8.4)\\
&\bar{x}.. - 11.0
\end{aligned}
$$

where

$t = 1.30$ for $(27+27-2)$ degrees of freedom and a probability of 0.1.

$$
\begin{aligned}
C &= \sqrt{(.81/52 + 1/52)2046}\\
&= 8.4
\end{aligned}
$$

where s^2 is the value computed from the first stage results. The confidence limit is:

$12.4 - 11.0 = 1.4$

STEP 8. Interpretation: Because the limit is positive, the revegetated area has met the requirement for successful revegetation. The revegetated area yields 1.4 lb/acre more than the critical 90 percent of the reference area yield (90 percent confidence).

Example 3

STEP 1. We estimate that the reference area has a mean of 1500 lb/acre and a variance of 400. A value for d is selected as one-half 1 percent of the reference area mean. The d value is $15 \div 2 = 8$.

STEP 2. Compute the **minimum** sample size needed from the reference area using equation 1.

$$
\begin{aligned}
n_{11} &= (.81)(2.0^2)(400)/8^2\\
&= 1296/64\\
&= 20.3
\end{aligned}
$$

where $t = 2.0$

Multiply n_{11} by 1.5 or 2 to determine the number of first stage random samples. In this case, 30 to 40 samples should be taken from both the reference and revegetated areas.

STEP 3. 40 samples are obtained from both areas. Compute from table 19 and equation 2.

$$
\begin{aligned}
\bar{x}_{11} &= 1743 \qquad s_1^2 = 752\\
\bar{x}_{21} &= 1318 \qquad s_2^2 = 1114\\
s^2 &= (40-1)(752) + (40-1)(1114)/(40+40-2)\\
&= 72774/78\\
&= 933.0
\end{aligned}
$$

STEP 4. Find t with $(40+40-2)$ degrees of freedom and a probability of 0.1. Compute using equations 3, 4, and 5.

$$
\begin{aligned}
A &= 40(1.29^2)(933.0)\\
&= 62104.2\\
B &= 40(8^2) - (.81)(1.29^2)(933.0)\\
&= 2560 - 1257.6\\
&= 1302.4\\
n_{22} &= \frac{62104.2}{1302.4} - 40\\
&= 47.7 - 40\\
&= 7.7 \text{ or } 8
\end{aligned}
$$

STEP 5. The value of n_{22} is a reasonable sample size for the revegetated area. An additional sample of size 8 is obtained from the revegetated area, for the second stage.

STEP 6. The mean of the revegetated area for the second stage sample is computed to be 1,352. Next, compute the weighted mean for all sample means from both stages using equation 9.

$$
\begin{aligned}
\bar{x}.. &= (-.9)(1743) + (.83)(1318) + (.17)(1352)\\
&= -1568.7 + 1093.9 + 229.8\\
&= -245.0
\end{aligned}
$$

where

$$
\begin{aligned}
w_1 &= (-.9)40/40 = -.9\\
w_2 &= 40/48 = .83\\
w_4 &= 8/48 = .17\\
n_1. &= 40 + 0 = 40\\
n_2. &= 40 + 8 = 48
\end{aligned}
$$

STEP 7. Calculate the confidence limit using equation 10.

$\bar{x}_{..} - 1.29(6.2)$

$\bar{x}_{..} - 8.0$

where

$t = 1.29$ for $(40+40-2)$ degrees of freedom and a probability of 0.1.

$$C = \sqrt{[(.81/40) + (1/48)]933.0}$$
$$= 6.2$$

where s^2 is the value computed from the first stage results.

The confidence limit estimate is:

$-245.0 - 8.0 = -253.0$

STEP 8. Interpretation: Since the limit is negative, the revegetated area did not meet the requirement for successful revegetation. The revegetated area may yield as much as 253 lb/acre less than the critical 90 percent of the reference area (90 percent confidence).

Additional Considerations

If the statistical tests reveal that the revegetated area has not met the criteria for successful revegetation, it may be desirable to examine the possible causes.

1. Error resulting in data that does not represent the true populations (lacks accuracy) and/or that is not repeatable (lacks precision) could play a large part in arriving at a false conclusion when testing hypotheses or examining confidence limits. Error can manifest itself in several ways. The sample unit chosen may not have been representative of the vegetation type being selected for, or the sample unit may have been located on an ecotone or transition between vegetation types. Potentially this could increase the variability of the sample within a single sample unit as well as between the two sample units. In addition, the sampling methods selected may have been inappropriate for the vegetation type or site conditions. Finally, the collection and analysis of the data may have been biased or may have lacked precision. This could greatly increase the variability of data.

Error can easily be compounded. Each error has the ability to increase the magnitude of subsequent errors. If error is suspected, it may be necessary for the investigator to revise the sampling scheme.

2. The investigator may have chosen an unrealistic value of d, the acceptable amount of difference between the means. It may be necessary to try several different d values to find the one that best fits the sampling situations. In vegetation types with a high degree of inherent variability, the requirement that the mean production and cover of the vegetated area be within 90 percent of that of the reference area may be unrealistic in terms of the large numbers of samples required and the high degree of similarity needed between the reference and revegetated areas. However, unless the regulations are changed, the required percentage of the reference area mean cannot be changed.

The confidence level (α value) should not be lowered. The confidence level determines the amount of faith, or confidence, that the investigator can have in his estimate of cover, density, or production, and it is necessary to have a high degree of confidence in this estimate in order to draw valid conclusions.

PUBLICATIONS CITED

Avery, T. E. Forest measurements. 1st ed. New York: McGraw-Hill; 1967. 290 p.

Basile, J. V.; Hutchings, S. S. Twig diameter-length-weight relations for bitterbrush. J. Range Manage. 19: 34–38; 1966.

Bonham, C. D.; Larson, L. L.; Morrison, A. A survey of techniques for measurement of and diversity on coal lands in the West. Denver, CO: U.S. Department of the Interior, Office of Surface Mining, Region V. Contract No. J7090435; 1980.

Bray, J. R.; Curtis, J. T. An ordination of upland forest communities of southern Wisconsin. Ecol. Monogr. 27: 325-349; 1957.

Cook, C. W.; Bonham, C. D. Techniques for vegetation measurements and analysis for pre- and post-mining inventory. Range Science Series No. 28. Fort Collins, CO: Colorado State University, Department of Range Science; 1977. 94 p.

Dilworth, J. R. Log scaling and timber cruising. 2d ed. Corvallis, OR: Oregon State University Book Stores; 1964. 446 p.

Dyksterhuis, E. J. Condition and management of range land based on quantitative ecology. J. Range Manage. 2: 104–114; 1949.

Greig-Smith, P. Quantitative plant ecology. 2d ed. London: Butterworth; 1964. 256 p.

Hovind, H. J.; Rieck, C. E. Basal area and point-sampling interpretation and applications. Tech. Bull. No. 23. Madison, WI: Department of Natural Resources; 1970.

Jensen, C. H.; Urness, P. J. Establishing browse utilization from twig diameters. J. Range Manage.; In press.

Joint Committee of the American Society of Range Management and the Agricultural Board. Basic problems and techniques in range research. Publ. No. 890. Washington, DC: National Academy of Sciences—National Research Council; 1962. 341 p.

Knight, D. H. Methods for sampling vegetation. An instruction manual. Laramie, WY: University of Wyoming, Department of Botany, Ark Industries; 1978. 87 p.

Motyka, J.; Dobrzanski, B. ; Zawadski, S. Wstepne badanla nad lakami paludniowo-wschodneij Lubelszczyzny. [Preliminary studies on meadows in the southwest province Lublin.] Ann. Univ. M Curie-Sklowdowska, Sec. E5: 367-447; 1950.

Mueller-Dombois, D.; Ellenberg, H. Aims and methods of vegetation ecology. New York: John Wiley and Sons; 1974. 547 p.

Olds, E. G. Distribution of sums of squares of rank differences for small samples. Ann. Math. Stat. 9: 133–148; 1938.

Peet, R. K. The measurement of species diversity. Annu. Rev. Ecol. Syst. 5: 285–307; 1974.

Pielou, E. C. The measurement of diversity in different types of biological collections. J. Theor. Biol. 13: 131–144; 1966.

Pielou, E. C. Population and community ecology. Principles and methods. New York: Gordon and Breach Science Publishers; 1974. 424 p.

Pielou, E. C. Ecological diversity. New York: John Wiley and Sons; 1975. 165 p.

Pieper, R. D. Measurement techniques for herbaceous and shrubby vegetation. Las Cruces, NM: New Mexico State University, Department of Animal, Range, and Wildlife Sciences, 1973. 187 p.

Shiue, C. Systematic sampling with multiple random starts. For. Sci. 6: 42–50; 1960.

Smith, A. D.; Urness, P. J. Analyses of the twig length method of determining utilization of browse. Publ. No. 62-9. Salt Lake City, UT: Utah State Department of Fish and Game; 1962.

Snedecor, G. W.; Cochran, W. G. Statistical methods. 5th ed. Ames, IO: Iowa State University Press; 1967. 593 p.

Society for Range Management. A glossary of terms used in range management. 2d ed. M. M. Kotham, ed. Denver, CO: Belke Printing; 1974. 36 p.

Sokal, R. R.; Rohlf, F. J. Biometry. San Francisco: W. H. Freeman; 1969. 776 p.

Spatz, G. Pflanzengesell schaften Leistung und Leistung spotential von Allgäüer Alpweiden in Abhangig keit von Standort und Bewirtschaftung. Munich: Technologische Universitat; 1970. 160 p. Dissertation.

Steele, R.; Cooper, S. V.; Ondov, D. M.; Pfister, R. D. Forest habitat types of Eastern Idaho-Western Wyoming. Review draft. Boise, ID: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station, Forestry Sciences Laboratory; 1979.

Steward, M. The use of a similarity index in evaluating reclamation success. Proc. of the Western Reclamation Group Workshop; Denver, CO, April 28–29, 1982. In press.

't Mannetje, L. Measurement of grassland vegetation and animal production. Bull. 52. Aurley, Berkshire, England: Commonwealth Bureau of Pastures and Field Crops; 1978. 260 p.

U.S. Department of Agriculture, Forest Service. Range environmental analysis. Rocky Mountain Region. For. Serv. Handb. 2209.21. Forest Service, Rocky Mountain Region; 1968.

U.S. Department of Agriculture, Soil Conservation Service. National range handbook. NRH-1. Washington, DC: U.S. Department of Agriculture, Soil Conservation Service; 1976.

U.S. Department of the Interior, Bureau of Land Management. Manual 4412 - Physical resource studies. Section 4412.14 – Soil-vegetation inventory method. Washington, DC: U.S. Department of Agriculture; 1979. 55 p.

Van Dyne, G. M.; Vogel, W. G.; Fisser, H. G. Influence of plot size and shape on range herbage production estimates. Ecology. 44: 746–759; 1963.

Whittaker, R. H. Dominance and diversity in land plant communities. Science. 147: 250–260; 1965.

Whittaker, R. H. Evolution and measurement of species diversity. Taxon. 21(2/3): 213–251; 1972.

OTHER REFERENCES

Avery, T. E. Interpretation of aerial photographs. 3d ed. Minneapolis, MN: Burgess Publishing; 1972. 392 p.

Avery, T. E. Natural resource measurements. 2d ed. New York: McGraw-Hill; 1975. 337 p.

Brown, D. Methods of surveying and measuring vegetation. Bull. No. 42. Hurley, Berkshire, England: Commonwealth Bureau of Pastures and Field Crops; 1954. 223 p.

Burr, R. D. The use of aerial photographs. Tech. Note 287. Denver, CO: U. S. Department of the Interior, Bureau of Land Management; 1976.

Chapman, S. B., ed. Methods in plant ecology. Oxford, England: Blackwell Scientific; 1976. 536 p.

Haber, A.; Runyon, R. P. General statistics. London: Addison-Wesley; 1969. 35 p.

Lommasson, T.; Jenson, C. Determining utilization of range grasses from height-weight tables. J. For. 41: 589–593; 1943.

Lyon, J. L. An evaluation of density sampling methods in a shrub community. J. Range Manage. 21: 16–20; 1968.

Mendenhall, W. Introduction to probability and statistics. 3d ed. Belmont, CA: Duxbury Press; 1971. 466 p.

Mosteller, F.; Rourke, R. E. Sturdy statistics. London: Addison-Wesley; 1973. 395 p.

Ostle, B.; Mensing, R. W. Statistics in research. 3d ed. Ames, IO: Iowa State University Press; 1975. 596 p.

Ott, L. An introduction to statistical methods and data analysis. North Scituate, MA: Duxbury Press; 1977. 730 p.

Pearson, E. S.; Hoartley, H. O. Biometrika tables for statisticians. v. 1. Cambridge, Great Britain: University Press; 1954. 238 p.

Stein, C. A two-sample test for a linear hypothesis whose power is independent of the variance. Ann. Math. Stat. 16: 243; 1945.

APPENDIX I

§ 816.111 Revegetation: General requirements.

(a) Each person who conducts surface mining activities shall establish on all affected land a diverse, effective, and permanent vegetative cover of the same seasonal variety native to the area of disturbed land or species that supports the approved postmining land use. For areas designated as prime farmland, the requirements of 30 CFR 823 shall apply.

(b) All revegetation shall be in compliance with the plans submitted under 30 CFR 780.18 and 780.23, as approved by the regulatory authority in the permit, and carried out in a manner that encourages a prompt vegetative cover and recovery of productivity levels compatible with the approved postmining land use.

(1) All disturbed land, except water areas and surface areas of roads that are approved as a part of the postmining land use, shall be seeded or planted to achieve a permanent vegetative cover of the same seasonal variety native to the area of disturbed land.

(2) The vegetative cover shall be capable of stabilizing the soil surface from erosion.

(3) Vegetative cover shall be considered of the same seasonal variety when it consists of a mixture of species of equal or superior utility for the approved postmining land use, when compared with the utility of naturally-occurring vegetation during each season of the year.

(4) If both the premining and postmining land uses are cropland, planting of the crops normally grown will meet the requirements of Paragraph (b)(1) of this Section.

§ 816.112 Revegetation: Use of introduced species.

Introduced species, may be substituted for native species only if approved by the regulatory authority under the following conditions:

(a) After appropriate field trials have demonstrated that the introduced species are desirable and necessary to achieve the approved postmining land use;

(b) The species are necessary to achieve a quick, temporary, and stabilizing cover that aids in controlling erosion; and measures to establish permanent vegetation are included in the approved plan submitted under Sections 780.18(b)(3) and 780.23.

(c) The species are compatible with the plant and animal species of the region;

(d) The species meet the requirements of applicable State and Federal seed or introduced species statutes and are not poisonous or noxious.

§ 816.113 Revegetation: Timing.

Seeding and planting of disturbed areas shall be conducted during the first normal period for favorable planting conditions after final preparation. The normal period for favorable planting shall be that planting time generally accepted locally for the type of plant materials selected. When necessary to effectively control erosion, any disturbed area shall be seeded and planted, as contemporaneously as practicable with the completion of backfilling and grading, with a temporary cover of small grains, grasses, or legumes until a permanent cover is established.

§ 816.114 Revegetation: Mulching and other soil stabilizing practices.

(a) Suitable mulch and other soil stabilizing practices shall be used on all regraded and topsoiled areas to control erosion, promote germination of seeds, or increase the moisture-retention capacity of the soil. The regulatory authority may, on a case-by-case basis, suspend the requirement for mulch, if the permittee can demonstrate that alternative procedures will achieve the requirements of 816.116 and do not cause or contribute to air or water pollution.

(b) When required by the regulatory authority, mulches shall be mechanically or chemically anchored to the soil surface to assure effective protection of the soil and vegetation.

(c) Annual grasses and grains may be used alone, as in situ mulch, or in conjunction with another mulch, when the regulatory authority determines that they will provide adequate soil erosion control and will later be replaced by perennial species approved for the postmining land use.

(d) Chemical soil stabilizers alone, or in combination with appropriate mulches, may be used in conjunction with vegetative covers approved for the postmining land use.

§ 816.115 Revegetation: Grazing.

When the approved postmining land use is range or pasture land, the reclaimed land shall be used for livestock grazing at a grazing capacity approved by the regulatory authority approximately equal to that for similar non-mined lands, for at least the last two full years of liability required under Section 816.116(b).

§ 816.116 Revegetation: Standards for success.

(a) Success of revegetation shall be measured by techniques approved by the regulatory authority after consultation with appropriate State and Federal agencies. Comparison of ground cover and productivity may be made on the basis of reference areas or through the use of technical guidance procedures published by USDA or USDI for assessing ground cover and productivity. Management of the reference area, if applicable, shall be comparable to that which is required for the approved postmining land use of the permit area.

(b) (1) Ground cover and productivity of living plants on the revegetated area within the permit area shall be equal to the ground cover and productivity of living plants on the approved reference area or to the standards in other technical guides approved by the Director for use in the regulatory program. The period of extended responsibility under the performance bond requirements of Subchapter J initiates when ground cover equals the approved standard after the last year of augmented seeding, fertilizing, irrigation or other work which ensures success in—

(i) Areas of more than 26.0 inches average annual precipitation; and continues for not less than five years. Ground cover and productivity shall equal the approved standard for the last two consecutive years of the responsibility period; or in

(ii) Areas of less than or equal to 26.0 inches average annual precipitation; and continues for not less than 10 years. Ground cover and productivity shall equal the approved standard for the last two consecutive years of the responsibility period.

(2) For purposes of paragraph (b)(1) of this Section, the average annual precipitation can be determined either—

(i) By interpolation, using standard techniques, from 'Mean Annual Precipitations,' Map, p. 97, The National Atlas of the United States, U.S. Department of the Interior, Geological Survey, 1970; or from 'Climatic Atlas of the United States,' U.S. Dept. of Commerce, National Oceanic and Atmospheric Administration, 1974; or from long-term precipitation averages from 'Climatological Data,' U.S. Dept. of Commerce, National Oceanic and Atmospheric Administration; or from other official records; or

(ii) Based on 10 years of continuous and reliable precipitation records from stations located in or adjacent to the mine plan area.

(3) The ground cover and productivity of the revegetated area shall be considered equal if they are at least 90 percent of the ground cover and productivity of the reference area with 90 percent statistical confidence, or with 80 percent statistical confidence on shrublands, or ground cover and productively are at least 90 percent of the standards in a technical guide approved pursuant to 30 CFR 816.116(b)(1). Exceptions may be authorized by the regulatory authority under the following standards:

(i) For previously mined areas that were not reclaimed to the requirements of this Subchapter, as a minimum the ground cover of living plants shall not be less than can be supported by the best available topsoil or other suitable material in the reaffected area, shall not be less than the ground cover existing before redisturbance, and shall be adequate to control erosion;

(ii) For areas to be developed for industrial or residential use less than 2 years after regrading is completed, the ground cover of living plants shall not be less than required to control erosion; and

(iii) For areas to be used for cropland, success in revegetation of cropland shall be determined on the basis of crop production from the mined area as compared to approved reference areas or other technical guidance procedures. Crop production from the mined area shall be equal to or greater than that of the approved standard for the last two consecutive growing seasons of the 5 or 10 year liability period established in (b)(1) of this Section. The applicable 5 or 10 year period of responsibility for revegetation shall commence at the date of initial planting of the crop being grown. Production shall not be considered equal if it is less than 90 percent of the production of the approved standard with 90 percent statistical confidence.

(iv) On areas to be developed for fish and wildlife management or forestland, success of vegetation shall be determined on the basis of tree, shrub or half-shrub stocking and ground cover. The tree, shrub, or half-shrub stocking shall meet the standards described in Section 816.117. The area seeded to a ground cover shall be considered acceptable if it is at least 70 percent of the ground cover of the reference areas with 90 percent statistical confidence or if the ground cover is determined to be adequate to control erosion by the regulatory authority. Section 816.116(b) shall determine the responsibility period and the frequency of ground cover measurement.

(c) The person who conducts surface mining activities shall—

(1) Maintain any necessary fences and proper management practices; and

(2) Conduct periodic measurements of vegetation, soils, and water prescribed or approved by the regulatory authority, to identify conditions during the applicable period of liability specified in Paragraph (b) of this Section.

(d) For permit areas 40 acres or less in size, in locations with an average annual precipitation of more than 26 inches, the following performance standards, if approved by the regulatory authority, may be used instead of reference areas to measure success of revegetation on sites that are disturbed. These standards shall be met for a minimum of 5 full consecutive years.

(1) Areas planted only in herbaceous species shall sustain a vegetative ground cover of 70 percent for 5 full consecutive years.

(2) Areas planted with a mixture of herbaceous and woody species shall sustain a herbaceous vegetative ground cover of 70 percent for 5 full consecutive years and 400 woody plants per acre after 5 years. On steep slopes, the minimum number of woody plants shall be 600 per acre.

(3) For purposes of this Section, herbaceous species means grasses, legumes, and nonleguminous forbs; woody plants means woody shrubs, trees and vines; and ground cover means the area of ground covered by the combined aerial parts of vegetation and the litter that is produced naturally onsite, expressed as a percentage of the total area of measurement.

§ 816.117 Revegetation: Tree and shrub stocking for forest land.

This Section sets forth forest resource conservation standards for reforestation operations to ensure that a cover of commercial tree species, noncommercial tree species, shrubs or half shrubs, sufficient for adequate use of the available growing space, is established after surface mining activities.

(a) Stocking, i.e. the number of stems per unit area, will be used to determine the degree to which space is occupied by well-distributed, countable trees, shrubs or half-shrubs.

(1) Root crown or root sprouts over 1 foot in height shall count as one toward meeting the stocking requirements. Where multiple stems occur only the tallest stem will be counted.

(2) A countable tree or shrub means a tree that can be used in calculating the degree of stocking under the following criteria:

(i) the tree or shrub shall be in place at least 2 growing seasons,

(ii) the tree or shrub shall be alive and healthy, and

(iii) the tree or shrub shall have at least one third of its length in live crown.

(3) Rock areas, permanent road and surface water drainage ways on the revegetated area shall not require stocking.

(b) The following are the minimum performance standards for areas where commercial forest land is the approved postmining land use:

(1) The area shall have a minimum stocking of 450 trees or shrubs per acre,

(2) A minimum of 75 percent of countable trees or shrubs shall be commercial trees species,

(3) The number of trees or shrubs and the ground cover shall be determined using procedures described in Sections 816.116(b)(3)(iv) and 816.117(a) and the sampling method approved by the regulatory authority; when the stocking is equal to or greater than 450 trees or shrubs per acre and there is acceptable groundcover, the 5 or 10 year responsibility period required in Section 816.116(b) shall begin;

(4) Upon expiration of the 5 or 10 year responsibility period and at the time of request for bond release, each permittee shall provide documentation showing that the stocking of trees and shrubs and the groundcover on the revegetated area satisfy Sections 816.116(b)(3)(iv) and 816.117(c)(i).

(c) The following are the minimum performance standards for areas where woody plants are used for wildlife management, recreation, shelter belts, or forest uses other than commercial forest land:

(1) An inventory of trees, half-shrubs and shrubs shall be conducted on established reference areas according to methods approved by the regulatory authority; this inventory shall contain but not be limited to—

(i) site quality,

(ii) stand size,

(iii) stand condition,

(iv) site and species relations, and

(v) appropriate forest land utilization considerations.

(2) The stocking of trees, shrubs, half-shrubs and the groundcover established on the revegetated area shall approximate the stocking and ground cover on the reference area and shall utilize local and regional recommendations regarding species composition, spacing and planting arrangement. The stocking of live woody plants shall be equal to or greater than 90 percent of the stocking of woody plants of the same life form on the reference area. When this requirement is met and acceptable ground cover is achieved, the 5 or 10 year responsibility period required in Section 816.116(b) shall begin.

(3) Upon expiration of the 5 or 10 year responsibility period and at the time of request for bond release, each permittee shall provide documentation showing that:

(i) the woody plants established on the revegetated site are equal to or greater than 90 percent of the stocking of live woody plants of the same life form of the approved reference areas with 80 percent statistical confidence and

(ii) the groundcover on the revegetated area satisfies Section 816.116(b)(3)(iv). Species diversity, seasonal variety and regenerative capacity of the vegetation of the revegetated area shall be evaluated on the basis of the results which could reasonably be expected using the revegetation methods described in the mining and reclamation plan.

§ 816.131 Cessation of operations: Temporary.

(a) Each person who conducts surface mining activities shall effectively secure surface facilities in areas in which there are no current operations, but in which operations are to be resumed under an approved permit. Temporary abandonment shall not relieve a person of their obligation to comply with any provisions of the approved permit.

(b) Before temporary cessation of mining and reclamation operations for a period of thirty days or more, or as soon as it is known that a temporary cessation will extend beyond 30 days, persons who conduct surface mining activities shall submit to the regulatory authority a notice of intention to cease or abandon mining and reclamation operations. This notice shall include a statement of the exact number of acres which will have been affected in the permit area, prior to such temporary cessation, the extent and kind of reclamation of those areas which will have been accomplished, and identification of the backfilling, regrading, revegetation, environmental monitoring, and water treatment activities that will continue during the temporary cessation.

§ 816.132 Cessation of operations: Permanent.

(a) Persons who cease surface mining activities permanently shall close or backfill or otherwise permanently reclaim all affected areas, in accordance with this Chapter and the permit approved by the regulatory authority.

(b) All underground openings, equipment, structures, or other facilities not required for monitoring, unless approved by the regulatory authority as suitable for the postmining land use or environmental monitoring, shall be removed and the affected land reclaimed.

§ 816.133 Postmining land use.

(a) *General.* All affected areas shall be restored in a timely manner —

(1) To conditions that are capable of supporting the uses which they were capable of supporting before any mining; or

(2) To higher or better uses achievable under criteria and procedures of this Section.

(b) *Determining pre-mining use of land.* The pre-mining uses of land to which the postmining land use is compared shall be those uses which the land previously supported, if the land had not been previously mined and had been properly managed.

(1) The postmining land use for land that has been previously mined and not reclaimed shall be judged on the basis of the highest and best use that can be achieved and is compatible with surrounding areas.

(2) The postmining land use for land that has received improper management shall be judged on the basis of the pre-mining use of surrounding lands that have received proper management.

(3) If the premining use of the land was changed within 5 years of the beginning of mining, the comparison of postmining use to premining use shall include a comparison with the historic use of the land as well as its use immediately preceding mining.

(c) *Prior to the release of lands from the permit area* in accordance with 807.12(c) the permit area shall be restored, in a timely manner, either to conditions capable of supporting the uses they were capable of supporting before any mining or to conditions capable of supporting approved alternative land uses. Alternative land uses may be approved by the regulatory authority after consultation with the landowner or the land-management agency having jurisdiction over the lands, if the following criteria are met:

(1) The proposed postmining land use is compatible with adjacent land use and, where applicable, with existing local, State, or Federal land use policies and plans: A written statement of the views of the authorities with statutory responsibilities for land use policies and plans is submitted to the regulatory authority within 60 days of notice by the regulatory authority and before surface mining activities begin. Any required approval, including any necessary zoning or other changes required for land use by local, State, or Federal land management agencies, is obtained and remains valid throughout the surface mining activities.

(2) Specific plans are prepared and submitted to the regulatory authority which show the feasibility of the postmining land use as related to projected land use trends and markets and that include a schedule showing how the proposed use will be developed and achieved within a reasonable time after mining and will be sustained. The regulatory authority may require appropriate demonstrations to show that the planned procedures are feasible, reasonable, and integrated with mining and reclamation, and that the plans will result in successful reclamation.

(3) Provision of any necessary public facilities is ensured as evidenced by letters of commitment from parties other than the person who conducts surface mining activities, as appropriate, to provide the public facilities in a manner compatible with the plans submitted under 30 CFR 780.23. The letters shall be submitted to the regulatory authority before surface mining activities begin.

(4) Specific and feasible plans are submitted to the regulatory authority which show that financing, attainment and maintenance of the postmining land use are feasible and, if appropriate, are supported by letters of commitment from parties other than the person who conducts the surface mining activities.

(5) Plans for the postmining land use are designed under the general supervision of a registered professional engineer, or other appropriate professional, who will ensure that the plans conform to applicable accepted standards for adequate land stability, drainage, vegetative cover, and esthetic design appropriate for the postmining use of the site.

(6) The proposed use will neither present actual or probable hazard to public health or safety nor will it pose any actual or probable threat of water flow diminution or pollution.

(7) The use will not involve unreasonable delays in reclamation.

(8) Necessary approval of measures to prevent or mitigate adverse effects

on fish, wildlife, and related environmental values and threatened or endangered plants is obtained from the regulatory authority and appropriate State and Federal fish and wildlife management agencies have been provided a 60 day period in which to review the plan before surface mining activities begin.

(9) Proposals to change pre-mining land uses of range, fish and wildlife habitat, forest land, hayland, or pasture to a postmining cropland use, where the cropland would require continuous maintenance such as seeding, plowing, cultivation, fertilization, or other similar practices to be practicable or to comply with applicable Federal, State, and local laws, are reviewed by the regulatory authority to ensure that —

(i) There is a firm written commitment by the person who conducts surface mining activities or by the landowner or land manager to provide sufficient crop management after release of applicable performance bonds under Subchapter J and Sections 816.111-816.117, to assure that the proposed postmining cropland use remains practical and reasonable;

(ii) There is sufficient water available and committed to maintain crop production; and

(iii) Topsoil quality and depth are sufficient to support the proposed use.

APPENDIX II

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as of
April 1981

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APPENDIX III

Scales and Equivalents (Maps and Photographs)

Scales and Equivalents (Maps and Photographs)

Scale	Feet per Inch	Inches per 1000 Feet	Inches per Mile	Miles per Inch	Meters per Inch	Acres per Square Inch	Square Inches per Acre	Square Miles per Square Inch	CM per KM
1: 500	41.667	24.000	126.720	0.008	12.700	0.0399	25.0910	0.00006	200.000
1: 600	50.000	20.000	105.600	0.009	15.240	0.0574	17.4240	0.00009	166.670
1: 1,000	83.333	12.000	63.360	0.016	25.400	0.1594	6.2730	0.00025	100.000
1: 1,200	100.000	10.000	52.800	0.019	30.480	0.2296	4.3560	0.00036	83.330
1: 1,500	125.000	8.000	42.240	0.024	38.100	0.3587	2.7880	0.00056	66.670
1: 2,000	166.667	6.000	31.680	0.032	50.800	0.6377	1.5680	0.00100	50.000
1: 2,400	200.000	5.000	26.400	0.038	60.960	0.9183	1.0890	0.00140	41.670
1: 2,500	208.333	4.800	25.344	0.039	63.500	0.9964	1.0040	0.00160	40.000
1: 3,000	250.000	4.000	21.120	0.047	76.200	1.4348	0.6970	0.00220	33.330
1: 3,600	300.000	3.333	17.600	0.057	91.440	2.0661	0.4840	0.00320	27.780
1: 4,000	333.333	3.000	15.840	0.063	101.600	2.5508	0.3920	0.00400	25.000
1: 4,800	400.000	2.500	13.200	0.076	121.920	3.6731	0.2720	0.00570	20.820
1: 5,000	416.667	2.400	12.672	0.079	127.000	3.9856	0.2510	0.00620	20.000
1: 6,000	500.000	2.000	10.560	0.095	152.400	5.7392	0.1740	0.00900	16.670
1: 7,000	583.333	1.714	9.051	0.110	177.800	7.8117	0.1280	0.01220	14.290
1: 7,200	600.000	1.667	8.800	0.114	182.880	8.2645	0.1210	0.01290	13.890
1: 7,920	660.000	1.515	8.000	0.125	201.168	10.0000	0.1000	0.01560	12.630
1: 8,000	666.667	1.500	7.920	0.126	203.200	10.2030	0.0980	0.01590	12.500
1: 8,400	700.000	1.429	7.543	0.133	213.360	11.2490	0.0890	0.01760	11.900
1: 9,000	750.000	1.333	7.041	0.142	228.600	12.9130	0.0770	0.02020	11.110
1: 9,600	800.000	1.250	6.600	0.152	243.840	14.6920	0.0680	0.02300	10.420
1: 10,000	833.333	1.200	6.336	0.158	254.000	15.9420	0.0630	0.02490	10.000
1: 10,800	900.000	1.111	5.867	0.170	274.321	18.5950	0.0540	0.02910	9.259
1: 12,000	1,000.000	1.000	5.280	0.189	304.801	22.9570	0.0440	0.03590	8.333
1: 12,500	1,041.662	0.960	5.069	0.197	317.505	24.9100	0.0400	0.03850	8.000
1: 13,200	1,100.000	0.909	4.800	0.208	335.281	27.7780	0.0360	0.04340	7.576
1: 14,400	1,200.000	0.833	4.400	0.227	365.761	33.0580	0.0300	0.05170	6.944
1: 15,000	1,250.000	0.800	4.224	0.237	381.001	35.8700	0.0280	0.05600	6.667
1: 15,600	1,300.000	0.769	4.062	0.246	396.241	38.7970	0.0260	0.06060	6.410
1: 15,840	1,320.000	0.758	4.000	0.250	402.337	40.0000	0.0250	0.06250	6.313
1: 16,000	1,333.333	0.750	3.960	0.253	406.400	40.8120	0.0240	0.06380	6.250
1: 16,800	1,400.000	0.714	3.771	0.265	426.721	44.9950	0.0220	0.07030	5.952
1: 18,000	1,500.000	0.667	3.520	0.284	457.201	51.6530	0.0190	0.08070	5.556
1: 19,200	1,600.000	0.625	3.300	0.303	487.681	58.7700	0.0170	0.09180	5.208
1: 20,000	1,666.667	0.600	3.168	0.316	508.002	63.7690	0.0160	0.09960	5.000
1: 20,400	1,700.000	0.588	3.106	0.322	518.161	66.3450	0.0150	0.10370	4.902
1: 21,120	1,760.000	0.568	3.000	0.333	536.449	71.1110	0.0140	0.11110	4.735
1: 21,600	1,800.000	0.556	2.933	0.341	548.641	74.3800	0.0130	0.11620	4.630
1: 22,800	1,900.000	0.526	2.779	0.360	579.121	82.8740	0.0120	0.12950	4.386
1: 24,000	2,000.000	0.500	2.640	0.379	609.601	91.8270	0.0110	0.14350	4.167
1: 25,000	2,083.333	0.480	2.534	0.395	635.001	99.6390	0.0100	0.15570	4.000
1: 31.680	2,640.000	0.379	2.000	0.500	804.674	160.0000	0.0060	0.25000	3.157
1: 33,333	2,777.778	0.360	1.901	0.526	846.683	177.1360	0.0056	0.38640	3.000
1: 48,000	4,000.000	0.250	1.320	0.758	1,219.202	367.3090	0.0030	0.57390	2.083
1: 50,000	4,166.667	0.240	1.267	0.789	1,270.025	398.5560	0.0025	0.62270	2.000
1: 62,500	5,208.333	0.192	1.014	0.986	1,587.503	622.7440	0.0016	0.97300	1.600
1: 63,360	5,280.000	0.189	1.000	1.000	1,609.347	640.0000	0.0016	1.00000	1.578
1: 75,000	6,250.000	0.160	0.845	1.184	1,905.038	896.7520	0.0011	1.40120	1.333
1: 96,000	8,000.000	0.125	0.660	1.515	2,438.405	1,469.2400	0.0007	2.29570	1.042
1: 100,000	8,333.333	0.100	0.634	1.578	2,540.050	1,594.2250	0.0006	2.49100	1.000
1: 125,000	10,416.667	0.096	0.507	1.973	3,175.006	2,490.9800	0.0004	3.89220	0.800
1: 126,720	10,560.000	0.095	0.500	2.000	3,218.694	2,560.0000	0.0004	4.00000	0.789
1: 250,000	20,833.333	0.048	0.253	3.946	6,350.012	9,963.9070	0.0001	15.56860	0.400
1: 253,440	21,120.000	0.047	0.250	4.000	6,437.389	10.244.2020	0.0001	16.00000	0.395
1: 300,000	25,000.000	0.040	0.211	4.735	7,620.015	14,348.0260	0.0001	22.41880	0.333
1: 500,000	41,666.667	0.024	0.127	7.891	12,700.025	39,855.6270	–	62.27440	0.200
1:1,000,000	83,333.333	0.012	0.063	15.783	25,400.050	159,422.5070	–	249.09770	0.100

October 1978

APPENDIX IV

SOURCES OF REMOTELY SENSED DATA

Compiled by
Applications Branch
EROS Data Center

NATIONAL CARTOGRAPHIC INFORMATION CENTER (NCIC)
(formerly the Map Information Office)

NCIC was established within the USGS to provide a single-point contact source for cartographic-related information, including remotely sensed data. A computerized indexing system, the Aerial Photography Summary Record System (APSRS), shows all holdings of Federal agencies, with the long range goal of including data acquired on the state and local levels and (eventually) by private industry.

The system directs the user to a particular agency which holds coverage over a particular unit area, based on the 7½ minute USGS quadrangle system. The data will remain in the hands of the source agency.

The cooperating Federal agencies include:

- U.S. Geological Survey (USGS)
- National Oceanic and Atmospheric Administration (NOAA)
- Agricultural Stabilization and Conservation Service (ASCS)
- Bureau of Land Management (BLM)
- National Archives and Records Service (NARS)
- U.S. Forest Service (USFS)
- Library of Congress, Geography and Map Division
- Soil Conservation Service (SCS)
- Tennessee Valley Authority (TVA)
- Department of Defense (DOD)
- U.S. Army Corps of Engineers (USACA)

To provide easier access to NCIC at the regional level, there are NCIC offices at four USGS mapping centers:

NCIC Eastern
U.S. Geological Survey
536 National Center
Reston, VA 22092
FTS: 928-6336
Comm: (703) 860-6336

NCIC Midcontinent
U.S. Geological Survey
1400 Independence Road
Rolla, MO 65401
FTS: 276-9107
Comm: (314) 364-3680

NCIC Rocky Mountain
U.S. Geological Survey
Stop 504, Box 25046
Denver Federal Center
Denver, CO 80225
FTS: 234-2326
Comm: (303) 234-2326

NCIC Western
U.S. Geological Survey
345 Middlefield Road
Menlo Park, CA 94025
FTS: 467-2427
Comm: (415) 323-2427

EROS DATA CENTER (EDC)

The EROS Data Center was established in 1971 as part of the Earth Resources Observation Systems (EROS) program of the Department of Interior, and is managed by the U.S. Geological Survey. It provides primary access to Landsat data, aerial photography acquired by the DOI, and aerial photography and other remotely sensed data acquired by NASA Research Aircraft and from Skylab, Apollo, and Gemini spacecraft.

Landsats 1, 2, and 3 have acquired approximately 280,000 individual scenes in four separate spectral bands. Nearly complete coverage of the world's land areas, except the polar areas, has been collected. Over 40,000 frames of Skylab, Apollo, and Gemini coverage have been archived at EDC. Only selected coverage was taken on these missions.

High altitude aerial photography (taken from 60,000 to 65,000 feet altitude) has been acquired by NASA for much of the United States at the request of investigators participating in the NASA Earth Resources Program. The most common scales are 1:60,000 and 1:120,000. Black-and-white, color, and color infrared photographs are generally available in a 9" film format. Since the inception of this program in 1964, approximately 1,300,000 frames have been acquired, covering about 80% of the contiguous 48 states. Many areas have been flown more than once. Main inputs for this data are the NASA-Ames Research Center in Moffett Field, California, and the NASA-Johnson Space Center in Houston, Texas.

Conventional aerial photography flown by the USGS accounts for approximately 2,000,000 frames. The most common scale is 1:24,000, typically on 9" black-and-white panchromatic film.

A final category includes aerial photography acquired by various Federal agencies at various scales and film types. The following groups have input approximately 1,000,000 frames into the EDC archives:

- Army Map Service, Air Force, Navy
- U.S. Army Corps of Engineers
- Bureau of Land Management
- Bureau of Reclamation
- Wallops and Marshall Flight Centers (NASA)
- Mississippi Test Facility
- University of Michigan
- South Dakota State University

Since the EROS Data Center does not hold the complete collection of aerial photography acquired by these individual groups, users should contact the originating agency for the possibility of additional coverage. For more information contact:

EROS Data Center
Attn: User Services
Sioux Falls, SD 57198
FTS: 784-7151
Comm: (605) 594-6511, Ext. 151

U.S. BUREAU OF LAND MANAGEMENT

The BLM acquired photography in recent years at various scales and film types. For more information, contact:

Mr. Wallace Crisco
Office of Special Mapping
Bureau of Land Management
Denver Federal Center
Building 50
Denver, CO 80225
FTS: 234-6036, 6037
Comm: (303) 234-6036, 6037

AGRICULTURAL STABLIZATION AND CONSERVATION SERVICE (ACSC)

The ASCS has acquired coverage over about 80% of the United States excluding Alaska. Most commonly, surveys are flown at a scale of 1:20,000 on black and white 9" panchromatic film. Coverage is usually flown on a county-by-county basis on a 7 year cycle, dating back to the 1930's. Since about 1971, 1:40,000 scale photography has been acquired. Indexes of coverage for specific areas are available for inspection through the local county ASCS office. For more information contact:

Aerial Photography Field Office
ASCS - USDA
2222 West 2300 South
P.O. Box 30010
Salt Lake City, UT 84125
FTS: 588-5856
Comm: (801) 524-5856

SOIL CONSERVATION SERVICE (SCS)

The SCS has acquired conventional aerial photography for many areas of the United States. Coverage was generally acquired at a scale of 1:20,000 on 9" black and white panchromatic film. Most recently, coverage has been acquired at scales ranging from 1:31,680 to 1:85,000. The SCS is currently undertaking orthophoto mapping projects with cooperation from the USGS. Surveys are not flown on a prescribed repetitive basis. For more information contact:

Soil Conservation Service, USDA
Cartographic Division
Federal Center Bldg.
Hyattesville, MD 20782
Comm: (301) 436-8187

NATIONAL ARCHIVES AND RECORDS SERVICE

This center is the archive for resource photography acquired by the ASCS, SCS, USGS, and the USBR prior to World War II. A catalog entitled "Aerial Photographs in the National Archives" is available upon request. For more information contact:

National Archives and Records Service
Cartographic Branch
General Services Administration
Washington, DC 20408
Tele: (205) 523-3006

U.S. FOREST SERVICE (USFS)

The USFS has acquired aerial photography over most of the National Forest lands. Photography is primarily at scales of 1:20,000 to 1:24,000 on standard black and white 9" panchromatic film, and dates back to 1934. Standard coverage through the 1960's was at a scale of 1:15,840. More recently, color and color IR photography at smaller scales ranging up to 1:80,000 has been acquired. Coverage is updated as is deemed necessary by the USFS.

The Forest Service is geographically organized into nine regions with the regional headquarters listed below.

Region 1
Northern
Federal Bldg.
Missoula, MT 59801

Region 2
Rocky Mt.
11177 W. 8th Ave.
Box 25127
Lakewood, CO 80225

Region 3
Southwestern
517 Gold Ave., SW
Albuquerque, NM 87102

Region 4
Intermountain
324 25th St.
Ogden, UT 84401

Region 5
California
630 Sansome St., Room 548
San Francisco, CA 94111

Region 6
Pacific Northwest
319 SW Pine St.
P.O. Box 3623
Portland, OR 97208

Region 7
Does not exist

Region 8
Southern
1720 Peachtree Rd.
Atlanta, GA 30309

Region 9
Eastern
633 West Wisconsin Ave.
Milwaukee, WI 53203

Region 10
Alaska
Federal Office Bldg.
P.O. Box 1628
Juneau, AK 99502

Inquires may also be referred to:

Division of Engineering
U.S. Forest Service, USDA
Washington, DC 20250

NATIONAL PARK SERVICE (NPS)

The NPS has acquired aerial photography over the national parks at various scales with film types. For more information contact:

National Park Service
Denver Service Center
655 Parfet St.
P.O. Box 25287
Denver, CO 80225
Tele: (303) 234-5132
FTS: 234-4500

ENVIRONMENTAL PROTECTION AGENCY (EPA)

In 1974 EPA established a Remote Sensing Branch at the National Environmental Research Center in Las Vegas, Nevada. The data acquired are of various types and formats. For more information contact:

Environmental Protection Agency
Remote Sensing Branch
P.O. Box 15027
Las Vegas, NV 89114

or: EPA Interpretation Center
P.O. Box 1587
Vint Hill Farms
Warrenton, VA 22186

DEPARTMENT OF DEFENSE (DOD)

Estimates of the amount of aerial photography acquired by the DOD run between 100 - 200 million frames. The primary agency responsible for archiving this collection is the Defense Intelligence Agency (DIA). Photograph was generally acquired by conventional means at scales of 1:15,000 - 1:40,000 on 9" black-and-white panchromatic film. Coverage dates back to the 1930's. Some of the early coverage, such as the AMS small scale coverage of the 1950's and the Navy/Army-acquired coverage of Alaska, has been transferred to the EDC archives. NCIC is currently handling the task of producing plots and indexes of DOD unclassified coverage.

The Defense Mapping Agency (DMA) was established in 1972, with primary responsibilities for mapping and charting within the DOD. Most current activities are being worked out in conjunction with the USGS.

For more information contact:

Defense Mapping Agency
Topographic Command
6500 Brooks Lane, NW
Washington, DC 20315
Att: Code 50320

Defense Intelligence Agency
Att: DS4A
Arlington Hall Station
Washington, DC 20301

U.S. ARMY CORPS OF ENGINEERS

The USACE has extensive involvement in civil projects such as dams, shoreline and flood protection, and waterway navigation. Aerial photographic coverage dating back to the 1930's was generally acquired with standard 9" black-and-white panchromatic film. Scales vary considerably with particular project requirements. More recently, coverage has been acquired using color and color IR film types. Although USACE is officially part of the DOD, most of its more recent coverage remains in the hands of the particular project office that collected it. The principal USACE organizations involved with remote sensing data are:

(A) Engineer Topographic Laboratories (ETL)
(B) Cold Regions Research and Engineering Laboratory (CRREL)
(C) Waterways Experiment Station (WES)
(D) Coastal Engineering Research Center (CERC)
(E) Construction Engineering Research Laboratory (CERL)
(F) Institute for Water Resources (IWR)

The Coastal Engineering Research Center at Ft. Belvoir, VA, has recently taken the responsibility of indexing much of the imagery collected by the Corps.

For more information, contact the USACE Remote Sensing Coordinator on the Division level.

Huntsville Division
William A. Newbern, Jr. - (HNDED-FC)
P.O. Box 1600 West Station
Huntsville, AL 35807
Tele: (205) 895-5190

Lower Mississippi Valley Division
Todd H. Riddle - (LMVED-G)
P.O. Box 80
Vicksburg, MS 39180
Tele: (601) 636-1311 ext. 339
or ext. 611

Missouri River Division
Charles G. Flagg-(MRDED-G)
P.O. Box 103 Downtown Station
Omaha, NE 68101
Tele: (402) 221-3204

New England Division
Joseph Horowitz - (NEDED-W)
424 Trapelo Road
Waltham, MA 92154
Tele: (617) 894-2400 ext. 632

North Atlantic Division
Dave Leiser - (NADPL-F)
90 Church Street
New York, NY 10007
Tele: (212) 264-7088

North Central Division
Mack L. Dixon - (NCDPD-PF)
536 S. Clark St.
Chicago, IL 60605
Tele: (312) 353-6395

North Pacific Division
Billy J. Thomas - (NPDEN-WC)
Room 210 Custom House
Portland, OR 97209
Tele: (503) 221-3757

Ohio River Division
Griffith Ray - (ORDED-T)
P.O. Box 1159
Cincinnati, OH 45201
Tele: (513) 684-3024

Pacific Ocean Division
Dr. James Maragos - (PODED-PV)
Bldg. 230, Ft. Shafter
Honolulu, HI 96813
Tele: (808) 438-2263

South Atlantic Division
James W. Erwin - (SADEG)
510 Title Bldg.
30 Pryor St. NW
Atlanta, GA 30303
Tele: (404) 526-6704

South Pacific Division
David L. Sveum - (SPDED-H)
630 Sansome St., Room 1216
San Francisco, CA 94111
Tele: (415) 556-5709

Southwestern Division
John W. Murchison - (SWDED-F)
1200 Main Tower
Dallas, TX 75202
Tele: (214) 749-3166

Field Operating Agencies

Coastal Engineering Research Center
Dennis Berg - (CERVE)
Kingman Bldg.
Ft. Belvoir, VA 22060
Tele: (703) 325-7172

Cold Regions Research and Engineering Laboratory
Dr. Duwayne Anderson
P.O. Box 282
Hanover, NH 03755
Tele: (603) 643-3200

Construction Engineering Research Laboratory
Dr. R. K. Jain
P.O. Box 4005
Champaign, IL 61820
Tele: (217) 352-6511

Robert Frost
Engineer Topographic Laboratories
Ft. Belvoir, VA 22060
Tele: (703) 664-3736

Institute for Water Resources
Kingman Bldg.
Ft. Belvoir, VA 22060

Waterways Experiment Station
Warren E. Grabau
P.O. Box 631
Vicksburg, MS 39180
Tele: (601) 636-3111

NATIONAL OCEAN SURVEY - COASTAL MAPPING DIVISION

The Coastal Mapping Division (formerly the Coast and Geodetic Survey) has acquired coverage over the nation's coastal areas. Multispectral metric mapping type coverage at scales ranging from 1:10,000 to 1:40,000 has been acquired in recent years. This agency also has the responsibility for acquiring aerial photography over the nation's major airports, back to World War II under the "Airport Obstruction Chart Survey Program." Coverage is typically black-and-white panchromatic with scales varying from 1:24,000 to 1:60,000. For more information contact:

Coastal Mapping Division
NOAA
Rockville, MD 20852
Tele: (301) 496-8601

DEFENSE METEOROLOGICAL SATELLITE PROGRAM (DMSP)

Data acquired by the USAF Global Weather Satellite Program is archived at the Space Science and Engineering Center at the University of Wisconsin. This data originates at USAF Global Weather Central, Offutt AFB, Omaha, NE. For more information contact:

DMSP Satellite Data Library
Space Science and Engineering Center
University of Wisconsin
1225 West Dayton Street
Madison, WI 53706
Tele: (608) 262-5335

WALLOPS FLIGHT CENTER (NASA)

Wallops Flight Center has an active remote sensing program centered around its Chesapeake Bay Ecological Program. Generally, this is low to middle altitude multispectral photography. For more information contact:

Chesapeake Bay Ecological
  Program Office
NASA-Wallops Flight Center
Wallops Island, VA 23337
Tele: (804) 824-3411 ext. 260

TENNESSEE VALLEY AUTHORITY

The TVA has acquired conventional aerial photography of the Tennessee River watershed area which includes the state of Tennessee and adjoining portions of Alabama, Georgia, Kentucky, Mississippi, North Carolina, and Virginia. Coverage, dating back to 1933, was taken at various scales although typically at 1:24,000. Recently, some special purpose color and color IR coverage has been acquired. For more information contact:

Map Information and Records Unit
Maps and Surveys Branch
Tennessee Valley Authority
101 Haney Bldg.
Chattanooga, TN 37401
Tele: (615) 755-2122

PRIVATE AERIAL SURVEY COMPANIES

If existing coverage is not suitable, it may be necessary to contract for new photography to be flown. A good source of names of aerial survey firms is:

American Society of Photogrammetry
105 North Virginia Avenue
Falls Church, VA 22046
Tele: (703) 534-6617

ENVIRONMENTAL SATELLITE IMAGERY

Low resolution imagery of the Earth is being acquired using visible and thermal infrared sensors by a variety of environmental satellites, including SMS-GOES, TIROS, Nimbus, ATS, and ESSA satellites. For more information contact:

Satellite Data Services Branch D543
Environmental Data Service
National Oceanic and Atmospheric
Administration (NOAA)
World Weather Bldg. - Room 606
Washington, DC 20233
Tele: (301) 763-8111

SOURCES OF REMOTELY SENSED DATA IN CANADA

For aerial photography, contact:

National Air Photo Library
615 Booth Street
Ottawa, Ontario K1A 0E9
Canada
Tele: (613) 995-4597
Telex: 053-4328

Landsat data can be purchased directly from:

Integrated Satellite Information Services
(ISIS) Ltd
P.O. Box 1630
Prince Albert, Saskatchewan S6V 5T2
Canada
Tele: (306) 764-3602 764-4259
Telex: 074-29242

Landsat data availability and ordering assistance (also information regarding airborne remotely sensed data) are provided by:

Canada Centre for Remote Sensing
Attn: User Assistance
717 Belfast Road
Ottawa, Ontario K1A 0Y7
Canada
Tele: (613) 995-1210
Telex: 053-3777

Regional NCIC and EROS Offices

1. National Cartographic Information Center (NCIC) - national headquarters

U.S. Geological Survey
National Cartographic Information Center
507 National Center
Reston, VA 22092
(703) 860-6045, FTS: 928-6045

2. NCIC Regional Mapping Centers

Mr. Raymond E. Hill
U.S. Geological Survey
Rocky Mountain Mapping Center
National Cartographic Information Center
Stop 510, Box 25046, Federal Center
Denver, CO 80225
(303) 234-2326, FTS: 234-2326

Mr. Frederick G. Lavery
U.S. Geological Survey
Eastern Mapping Center
National Cartographic Information
536 National Center
Reston, VA 22092
(703) 860-6336, FTS: 928-6336

Mr. Lee W. Aggers
U.S. Geological Survey
Western Mapping Center
National Cartographic Information Center
345 Middlefield Road
Menlo Park, CA 94025
(415) 323-8111, ext. 2427, FTS: 467-2427

Mr. William M. Voight
U.S. Geological Survey
Mid-Continent Mapping Center
National Cartographic Information Center
1400 Independence Road
Rolla, MO 65401
(314) 364-3680, ext. 107,
FTS: 276-9107

3. NCIC Federal Affiliate

Maurice Msarsa
Maps and Surveys Branch
Tennessee Valley Authority
200 Haney Building
311 Broad Street
Chattanooga, TN 37401
(615) 755-2148, FTS: 854-2148

4. NCIC Other Affiliates

Mr. Kent N. Swanjord
U.S. Geological Survey
EROS Data Center
Sioux Falls, SD 57198
(605) 594-6511, ext. 507,
FTS: 784-7507

Mr. Henry T. Svehlak
U.S. Geological Survey
National Space Technology Laboratories
National Cartographic Information Center
Building 1100
NSTL Station, MS 39529
(601) 688-3544, FTS: 494-3544

5. NCIC State Affiliates

Arizona

Mr. Michael S. Castro
Arizona Department of Revenue
Arizona Resources Information System
1624 West Adams, Room 302
Phoenix, AZ 85007
(602) 271-4061, FTS: 765-4061

Georgia

Mr. Keith McConnell
Branch of Geology and Water Resources
Geologic & Water Resources Division
Department of Natural Resources
19 Martin Luther King Drive
Atlanta, GA 30334
(404) 656-3214, FTS: 656-3214

Minnesota

Dr. Donald Yeager
Minnesota State Planning Agency
Environmental State Planning Agency
15 Capitol Square
550 Cedar Street
St. Paul, MN 55101
(612) 296-2613, FTS: 776-2613

New Mexico

Dr. Stanley A. Morain
Technology Applications Center
University of New Mexico
2500 Central Avenue, SE
Albuquerque, NM 87131
(505) 277-3622

Pennsylvania

Mr. Don Hoskins
Department of Environmental Resources
Room 916 Executive House
Bureau of Topographic and
Geological Survey
P.O. Box 2357
Harrisburg, PA 17120
(717) 787-2169, FTS: 637-2169

South Carolina

Mr. Nick Bayne
South Carolina Land Resources
Conservation Commission
2221 Devine Street, Suite 222
Columbia, SC 29205
(803) 758-7197, ext. 41

Tennessee

Mr. Ron Zurawski
Tennessee Division of Geology
Room G-5
State Office Building
Nashville, TN 37219
(615) 741-2726, FTS: 840-2726

Texas

Mr. David L. Ferguson
Texas Natural Resources Information
System
P.O. Box 13087
Austin, TX 78711
(512) 475-3321, FTS: 734-5011

Utah

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orgia Resource Assessment Program	Bruce Rado	(404) 656-5164
wa Water Resources Data System (IWARDS)	Bernie Hoyer	(319) 338-1173
uisana Areal Resource Information System (LARIS)	Glenn Daigre	(504) 925-4585
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w Jersey Geographic Base File	Bob Mills	(609) 292-2855
w York Land Use and Natural Resources Inventory (LUNR)	Chuck Guinn	(518) 474-7690
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APPENDIX V

SELECTED BOOKS ON MAPS AND MAPPING

All About Maps and Mapping
Susan Marsh; Random House, 1963.
Be Expert With Map and Compass: The Orienteering Handbook
Bjorn Kjellstrom; Scribner & Sons, 1976.
Cartographic Design and Production
J.S. Keates; Halsted Press, 1976.
Computers and the Renaissance of Cartography
T.A. Margerison; Her Majesty's Stationery Office, 1976.
Coordinate Systems and Map Projections
D.H. Maling; George Philip & Son, Ltd., 1973.
Easy Steps to Map Reading
Kathleen Howard; J.M. Dent & Sons, Ltd., 1958.
Elementary Map Reading
Thomas Pickles; J.M. Dent & Sons, Ltd., 1950.
Elements of Cartography
A.H. Robinson, R.D. Sale, and J. Morrison; John S. Wiley & Sons, Inc., Third Edition, 1978.
Elements of Map Projection with Applications to Map and Chart Construction
U.S. Government Printing Office, 1931 (Reprint 1972).
Elements of Photogrammetry
P.R. Wolf, McGraw-Hill, 1974.
First Book of Maps and Globes
S. Epstein and B. Epstein; Franklin Watts, Inc., 1959.
General Cartography
Erwin Raisz; McGraw-Hill Book Co., 1948.
Going Places U.S.A.
William D. Pattison, Rand McNally and Co., 1977.
How Maps and Globes Help Us
David Hackler; Benefic Press, 1962.
Introduction to Mapwork
L.H. Williams; Allman and Son, 1968.
Introductory Map Reading
I.C. Marshall and A.H. Meux; Univ. of London Press, Ltd., 1966.
Landforms and Topographic Maps
William Bayley Upton, Jr.; John Wiley & Sons, 1970.
The Language of Topographic Maps
D.S. Biddle, A.K. Milne and D.A. Shortle; Jacaranda Press, Australia, 1974.
Learning to Use a Map
P.L. Ewing and R.O. Smith, A.J. Nystrom and Co., 1977.
Look at the Map
Cyril Midgley; Whitcombe and Tombs, Ltd., 1968.
The Magic Map
Cyril Midgley; Wheaton Publishing Co., 1967.
Manual of Photogrammetry
Morris M. Thompson; American Society of Photogrammetry, 1966.
Map and Globe Activities for Children
Paul F. Griffin; Fearon Publishers, Inc., 1957.
Map and Photo Reading
Thomas W. Birch; Edward Arnold, Ltd., 1968.
Map, Compass, and Campfire
Donald E. Ratliff; Binford and Mort, 1970.
A Map is a Picture
B. Rinkoff; Thomas Y. Crowell Co., 1965.
Mapmakers of America from the Age of Discovery to the Space Age
S. Carl Hirsch; Viking Press, 1970.
Map Making: The Art That Became A Science
Lloyd A. Brown; Little, Brown & Co., 1960.
Map Reading and Interpretation
P. Speak and A.H. Carter; Longmans, Ltd., 1970.
Map Reading for Schools
Margaret Wood; George G. Harrap & Co., Ltd., 1964.
Map Reading in Geography
Kenneth B. Cumberland; Whitcomb and Tombs, Ltd., 1968.
Map Reading through Map Making
D.D. Harris; Whitcomb and Tombs, Ltd., 1966.
Maps and Diagrams, Their Compilation and Construction
F.J. Monkhouse and H.R. Wilkinson; Methuen & Co., 1971.
Maps of the Ancient Sea Kings
C.H. Hapgood; Chilton Book Publishers, 1966.
Maps Mean Adventure
Cristle McFall; Dodd, Mead & Co., 1972.
The Map Unfolds
Cyril Midgley; Wheaton Publishing Co., 1969.
Mapping
David Greenhood; University of Chicago Press, 1964.
Mapping the World
Erwin Raisz; Abelard Schuman, Ltd., 1956.
Maps and Man
Norman J.W. Thrower; Prentice-Hall, Inc., 1972.
Maps and Mapping
B. Butterfield; Doubleday & Co., Inc., 1966.
Maps and Their Makers: An Introduction to the History of Cartography
G.R. Crone; Shoe String, 1977.
Math Projects: Map-Making
H.E. Tannenbaum and N. Stillman; Book Lab, Inc., 1968.
Physical Geography in Diagrams
R.B. Bunnett; Longmans, Ltd., 1973.
Principles of Cartography
Erwin Raisz, McGraw-Hill Book Co., 1962.
Rand McNally Handbook of Map and Globe Usage
Ruby M. Harris, Rand McNally and Co., 1967.
Reading Maps
Paul A. Riffel; Hubbard Press, 1973.
Reading Topographical Maps
A.H. Meux; Hodder Educational, 1975.
The Round Earth on Flat Paper
National Geographic Society, 1947.
The Story of Maps
M. Schere; Prentice Hall, Inc., 1969.
Surveying
Boy Scouts of America, 1960.
Surveying Practice: The Fundamentals of Surveying
Philip Kissam; McGraw-Hill, 1978.
Surveyors and Surveys of the Public Lands
Bureau of Land Management, Department of Interior; Government Printing Office, 1976.
Teaching About Maps Grade by Grade
Susan Marsh; Teachers Publishing Corps., 1965.
The True Book of Maps
Norman and Madelyn Carlisle; Childrens Press, 1969.
The World of Maps and Mapping
Judith Tyner; McGraw-Hill, 1973.

APPENDIX VI

A Set of Random Numbers

Column 1	Column 2	Column 3	Column 4
6327	0983	3798	4679
2167	6484	9467	9058
5939	0407	1804	8827
4672	3865	5689	9878
8071	5185	5514	5308
9509	0603	7461	8550
6615	2588	3558	3349
4833	2422	9790	1183
5594	1809	6931	6571
9441	1699	3947	7702
7922	9812	7229	5252
9419	6494	8179	8065
6178	3556	2466	2495
2647	3961	7546	4799
0474	1839	6926	6534
9814	1577	8293	0301
0104	4579	0627	8667
1608	9470	4131	5345
9722	1557	0471	5498
4189	3582	3675	9461
9855	8088	9006	6897
5791	8234	1472	3421
0872	3310	0510	9046
8953	9809	8037	8376
2895	4319	6544	8953
0609	5248	8734	2498
9795	2464	6170	1063
1572	7371	7936	2841
4307	0294	6060	5194
4857	0197	2401	7005
1632	7189	6463	9830
0745	8034	7882	7152
0736	5110	5165	6571
8168	7924	5876	1407
7468	5313	2736	9010
6044	5420	3077	9070
6716	0059	3001	8871
9342	0169	6880	7986
5809	6048	9051	1151
1532	9715	7081	0109
5506	5812	5917	4415
4045	1751	2817	9958
5966	9930	6437	7279
6062	3296	5093	2503
4097	8379	5670	0614
6793	3999	4645	5143
7960	4853	0583	1920
1321	4067	8503	1604

APPENDIX VII

Changing the Statistical Procedures to Meet Changes in the Regulations

The procedures described in the section on ''Meeting Statistical Requirements'' are adaptable to changes in the regulations.

1. If the confidence level changes, from 0.1, it is merely necessary to look up t-values which correspond to the new level of confidence. For example, when $n = 25$, and the level of confidence is 0.1, $t = 1.32$ (table 20). If $n = 25$, and the level of confidence is 0.05, $t = 1.71$.

2. If the percent of the reference area that the cover and production of the revegetated area must fall within changes, it will be necessary to change all equations in which 0.9, 0.81, and 1.81 occur. Two examples are provided below. The original value and how it was derived is shown under the 90 percent column. The values that would be substituted for 85 percent or 100 percent are shown in the next two columns.

90 percent	85 percent	100 percent
0.9	0.85	1.0
$0.81 = 0.9^2$	$0.72 = 0.85^2$	$1.0 = 1.0^2$
$1.81 = 1 + 0.81$	$1.72 = 1 + 0.72$	$2.0 = 1.0 + 1.0$

☆ U.S. GOVERNMENT PRINTING OFFICE: 1983—676-032/1035 REGION NO. 8

Chambers, Jeanne C.; Brown, Ray W. Methods for vegetation sampling and anaysis on revegetated mined lands. Gen. Tech. Rep. INT-151. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1983. 57p.

This handbook details methods of sampling vegetation for the comparison of revegetated mine lands and reference areas as specified by Federal regulations. Reference area selection, sampling schemes, and species diversity are covered as well as production, cover, and density sampling methodology. A statistical section outlines sample size determination and comparison of reference and revegetated areas using confidence limit estimates.

KEYWORDS: revegetation, Federal regulations, sampling methodology, reference areas, cover, production, diversity, sample size, confidence limit estimates

The Intermountain Station, headquartered in Ogden, Utah, is one of eight regional experiment stations charged with providing scientific knowledge to help resource managers meet human needs and protect forest and range ecosystems.

The Intermountain Station includes the States of Montana, Idaho, Utah, Nevada, and western Wyoming. About 231 million acres, or 85 percent, of the land area in the Station territory are classified as forest and rangeland. These lands include grasslands, deserts, shrublands, alpine areas, and well-stocked forests. They supply fiber for forest industries; minerals for energy and industrial development; and water for domestic and industrial consumption. They also provide recreation opportunities for millions of visitors each year.

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Missoula, Montana (in cooperation with the University of Montana)

Moscow, Idaho (in cooperation with the University of Idaho)

Provo, Utah (in cooperation with Brigham Young University)

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United States
Department of
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Forest Service

Intermountain
Forest and Range
Experiment Station
Ogden, UT 84401

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August 1983

Proceedings—Research and Management of Bitterbrush and Cliffrose in Western North America

Salt Lake City, Utah, April 13-15, 1982

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U.S. DEPARTMENT OF AGRICULTURE

Proceedings— Research and Management of Bitterbrush and Cliffrose in Western North America

Salt Lake City, Utah, April 13-15, 1982

Compilers:

ARTHUR R. TIEDEMANN, Project Leader and Supervisory Range Scientist, U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station, Ogden, Utah.

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Proceedings of a symposium sponsored by the U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station, and Utah State University.

FOREWORD

Purshia and closely related genera such as Cowania and Fallugia of the Roseaceae are important components of vegetative habitats on approximately 25 million acres (10 million ha) in Western North America. They occupy successional positions ranging from seral to climax, and show specific adaptations to soil type, climate, and vegetation associations. They form the mainstay of the diet of wintering mule deer throughout much of their range and provide vital watershed protection to otherwise unstable erosive land. Because of the N-fixing capability of Purshia and Cowania, shrubs of these genera play a role in the nitrogen economy of habitats where they are found.

Through the past several decades, a substantial amount of research has been conducted in habitats where these shrubs occur. Management programs have intensified to explore their utilization for wildlife, range livestock, and revegetation. However, to date there has been no effort to assemble the existing knowledge of these shrubs and to bring this information to individuals involved in research and management.

The purpose of this symposium proceedings is to develop the state-of-the-art and science of managing these shrubs and to provide land managers, scientists, and educators with a reference text.

The Bitterbrush and Cliffrose Symposium, held in Salt Lake City, Utah, April 13-15, 1982, drew some 120 participants from land management agencies, colleges and universities, and Federal research organizations. The symposium was sponsored by the USDA Forest Service, Intermountain Forest and Range Experiment Station, Ogden, Utah, and Utah State University, Logan.

ACKNOWLEDGMENTS

The compilers wish to express their appreciation to four persons who were instrumental in assuring the quality and uniformity of papers in this proceedings: Roberta Powell, Provo Shrub Sciences Laboratory, for her assistance in assuring that manuscripts were in the proper format and style for submission; Louise Kingsbury, Intermountain Station, Ogden, for her diligent and careful editing; and Pat Van Drimmelen and Gloria Lamph, Ogden, for their precise design and layout work.

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WELCOMING REMARKS --

BITTERBRUSH AND CLIFFROSE SYMPOSIUM

Dr. Roger R. Bay

Director, Intermountain Forest and Range Experiment Station

I am pleased to see so many scientists and managers from throughout the Western United States here at this important symposium. Many of you have been involved in the study of, and the management of, bitterbrush and cliffrose for quite some time. We obviously believe these are important plant species and their proper management can contribute to better land and wildlife management. The Intermountain Forest and Range Experiment Station has had a variety of research effort on bitterbrush for well over 30 years, with some of the early work started in the Boise area in cooperation with other agencies. I think this symposium is timely.

I am pleased to see that many representatives of management agencies are involved with the program and are attending this meeting. Close working relationships between research groups and management agencies are a prime factor in moving technology from the study and discovery stage to application in the field. We at the Intermountain Station have had a particularly close working relationship with a variety of agencies involved in the management of bitterbrush. Here in Utah, the Utah Division of Wildlife Resources and the Station have worked together for more than 30 years, involving assignments of scientists and managers between the State division and our Shrub Sciences Laboratory in Provo. Not only do we cooperate in research studies, but the State's management agency ensures that results are put into practice immediately.

We've also enjoyed good cooperative work with other States such as the Idaho Department of Fish and Game, and the major Federal agencies, National Forest System, and the Bureau of Land Management in the Intermountain area. Such team work has contributed to our knowledge and management for the two important species we are addressing today.

The purpose of this symposium is to develop state-of-the-art information on the science and management of these shrubs, and to provide land managers, scientists, and educators with a reference text. This is certainly in keeping with one of our major goals at the Intermountain Station in recent years: to summarize, synthesize, and deliver to managers information about key subjects in the Intermountain and Rocky Mountain West area. We have been able to stress technology transfer efforts such as this only because we have been able to conduct the research studies over several decades. We have built up a reservoir of information from research as well as experience of managers. It is appropriate now to tap this reservoir and ensure that the knowledge is transferred to the right hands.

I hope this symposium will not be the only one of its kind. We have had some discussion on the possibility of continuing this kind of effort with other shrub species important to the Western United States. We would appreciate your thoughts and comments on this possibility.

We don't have any papers in the symposium addressing technology needs or the opportunities for future research. I would ask participants to consider this topic now and after this symposium. What are the new technology needs of resource managers? Where should the science agencies--such as Forest Service Research Stations, Agricultural Research Service, and universities--concentrate their future research efforts? The participants of this symposium represent the spectrum of agencies and institutions involved in both the research and management of shrub species. I hope you will have the opportunity to consider needs and agree on some recommended actions.

Section 1. Distribution, Taxonomy, and Habitat Classification

TAXONOMY, DISTRIBUTION, AND CYTOGENETICS OF PURSHIA, COWANIA, AND FALLUGIA (ROSOIDEAE, ROSACEAE)[1]

E. Durant McArthur, Howard C. Stutz, and Stewart C. Sanderson[2]

ABSTRACT

The rosaceous genera Cowania, Purshia, and Fallugia are endemic to western North America. The five species of Cowania (C. ericifolia, C. mexicana, C. plicata, C. stansburiana, C. subintegra) and the single species of Fallugia (F. paradoxa) are more southern in distribution (Mexico and southwestern United States) than the two species of Purshia (P. glandulosa, P. tridentata) which extend from northern Baja California to British Columbia. Hybridization between C. stansburiana and P. tridentata is common where their ranges are sympatric, principally in Utah and Nevada. They both have $n = 9$ chromosomes, F_1 hybrids between them are fertile and reciprocal introgression is common. Purshia glandulosa is considered to have been derived from such hybrid products. Fallugia paradoxa has $n = 14$ chromosomes. Polyploidy was not found in individuals of 22 Cowania; 64 Purshia; seven Purshia X Cowania interspecific and intergeneric hybrids; and six Fallugia populations. Chromosome counts are presented here for the first time for Cowania ericifolia, C. mexicana, C. plicata, C. subintegra, and Purshia glandulosa; all $n = 9$. The $n = 14$ count for Fallugia paradoxa is a corrected count, it was formerly reported as $n = 9$. During the early Tertiary, Cowania and Fallugia may have had a common ancestor in the northern Mexican uplands, or more likely Fallugia may have had a separate origin. Purshia may have been derived directly from Cowania which has more southern distribution, more primitive traits, and a larger number of species; or from a common ancestor. Cercocarpus shares many of the primitive traits of Cowania and may be related to Cowania and Purshia; it is abundant in the fossil record.

---

[1] Paper presented at the Bitterbrush and Cliffrose Symposium, Salt Lake City, Utah; April 13-15, 1982.

[2] E. Durant McArthur is Principal Research Geneticist, USDA Forest Service, Intermountain Forest and Range Experiment Station, Ogden, Utah 84401; stationed at the Shrub Sciences Laboratory, Provo, Utah 84601; and Adjunct Professor, Department of Botany and Range Science, Brigham Young University, Provo, Utah 84602. Howard C. Stutz is Professor, Department of Botany and Range Science, Brigham Young University, Provo, Utah 84602. Stewart C. Sanderson is Research Associate at the Shrub Sciences Laboratory and at Brigham Young and Wayne State Universities.

INTRODUCTION

Cowania, Purshia, and Fallugia have been included as members of the tribe Dryadeae of the subfamily Rosoideae of Rosaceae (Rydberg 1908-1918). In common with many rosaceous genera, the three genera are economically important (table 1, Robertson 1974). They provide browse for livestock and wild herbivores, seed production for small animals, natural and manipulated soil binding, and esthetic beauty (Robertson 1974, Blauer and others 1975). These genera have a Western United States distribution, more northerly in the case of Purshia, but distinctly southwestern, extending well into Mexico, for Cowania and Fallugia. The genera have distributional and morphological analogues consisting of other rosaceous genera principally from the subfamilies Rosoideae and Spiraeoideae.

Table 1.--Subfamilies of Rosaceae with characteristic chromosome numbers and generic examples[1]

Subfamily	Common x's	Other x's	Polyploidy present	Representative genera (x)
Rosoideae	7,9	8,14	Yes	Fragaria, Geum, Potentilla, Rosa, Rubus, Sanguisorba (7); Alchemilla, Coleogyne[2] (8); Cercocarpus, Chamaebatia[2], Cowania, Dryas, Purshia (9); Fallugia (14)
Prunoideae	8	--	Yes	Exochorda, Osmaronia, Prunus (8)
Spiraeoideae	9	7	Yes	Physocarpus, Spirea (7,9); Aruneus, Chamaebatiaria[2], Holodiscus[2], Kelysea[2], Petrophytum[2], Lutkea (9)
Pomoideae	17	14,15	Yes	Quillaja (14); Vaquelinia (15); Amelanchier, Cotoneaster, Crataegus, Malus, Peraphyllum[2], Pyracantha, Pyrus, Sorbus (17)

---

[1] References: Federov (1969), Ornduff (1967), Moore (1973, 1974, 1977), Goldblatt (1976, 1981), and tables 2 and 3.

[2] New chromosome counts (Sanderson and McArthur, unpublished).

In this paper we discuss the taxonomic and geographic settings of the group and present exhaustive chromosomal data. Based on those settings and data, we present hypotheses outlining possible evolutionary relationships.

FAMILY TAXONOMIC SETTING

The rose family consists of about 100 genera of herbs, shrubs, vines, and trees divided into 3,000 species not including apomictic microspecies of Rubus and Rosa and other genera (Robertson 1974; Bailey Hortorium Staff 1976). The family has usually bee divided into six subfamilies, but with the recognition of Chrysobalanaceae and Neuradaceae as independent families, only four subfamilies remain: Rosoideae, Prunoideae, Spiraeoideae, Pomoideae (Robertson 1974; Goldblatt 1976; Jones and Luchsinger 1979). The subfamilies are distinguished, in general, from one another by ovary position, type of flower, type of fruit, and number of pistils (Johnson 1931; Lawrence 1951; Benson 1957; Jones and Luchsinger 1979). Members of the family occur worldwide but are much more common in the northern temperate region--especially western North America and eastern Asia (Raven and Axelrod 1974). All 13 tribes occur in North America, 12 of 13 in western North America. A total of 45 genera have species indigenous to North America; 42 genera are restricted to North America (Robertson 1974)

The family Rosaceae is one of 17 families in the order Rosales. According to the Takhtajan-Cronquist phylogenetic classification system of flowering plants, the Rosales were derived from the primitive Magnoliales fairly early in angiosperm history (Cronquist 1968). The Rosaceae was well represented by Paleogene time some 50 million years ago (Raven and Axelrod 1974).

BASE CHROMOSOME NUMBERS IN ROSACEAE

The basic (x) chromosome number for the family Rosaceae and for the Rosales as a whole is thought to be $x = 9$, although $x = 7$ also draws some support (Raven 1975; Goldblatt 1976; Lewis 1980). Within the family, base numbers of 7, 8, 9, and 17 are common (table 1), which has invited considerable speculation from cytogeneticists about phylogenetic relationships. Sax (1933) proposed that ancient, $x = 8$ and $x = 9$, taxa hybridized and with the subsequent doubling of chromosome numbers, produced the amphidiploid Pomoideae with $x = 17$. Stebbins (1950) suggested that the $x = 8$ and $x = 9$ plants were from the subfamilies Prunoideae and Spiraeoideae, respectively. Darlington and Moffett (1930) and Darlington (1963) suggested an alternative cytological scenario for the Pomoideae: $x = 17$ is derived from an $x = 7$ base with three chromosomes present three times and the other four present two times. Goldblatt (1976) challenged the Prunoideae and Spiraeoideae hybridization hypothesis on the basis of chemotaxonomical data. Robertson (1974) and Goldblatt (1976) suggested that Spiraeoideae are likely the primitive Rosaceae.

CHROMOSOME NUMBERS IN *COWANIA*, *PURSHIA*, AND *FALLUGIA*

Previously reported chromosome counts on 21 populations of *Purshia tridentata* (Sanderson 1969; Alderfer 1976), two populations of *Cowania stansburiana* (Baldwin 1951; Sanderson 1969), and a single collection of *Fallugia* (Baldwin 1951) were all $n = 9$ or $2n = 18$ diploids. Sanderson (1969) reported that hybrids between *Purshia tridentata* and *Cowania stansburiana* were normal diploids with nine pairs of chromosomes at meiosis. Our new counts (table 2) confirm the $x = n = 9$ status for *Cowania* (5 species) and *Purshia* (2 species) for 205 individuals from 93 populations and 1 interspecific and 5 intergeneric hybrid populations. Our counts cover most of the geographic range for *Purshia* and for *Cowania stansburiana* (fig. 1, 2; table 2). For the other *Cowania* species we obtained counts, from 1 to 3 plants, from 1 population each (table 2). *Fallugia* is not based on $x = 9$. Our counts for 6 widespread populations (table 2) were all $n = 14$. Baldwin's (1951) count of $2n = 18$ is apparently an error. Baker, Righetti, and Pinkava (personal communication) also recently obtained $n = 14$ counts for *Fallugia*. Although polyploidy is quite common in the Rosaceae as a whole (table 1), it did not occur in the populations we sampled for *Purshia*, *Cowania*, or *Fallugia* (table 2).

EVOLUTIONARY CONSIDERATIONS

Although the family Rosaceae in general is circumboreal in distribution and many the taxa had Arcto-Tertiary distribution, several genera are richly represented in the Madro-Tertiary geoflora (Axelrod 1958). The Tertiary geoflora concept championed by Chaney and Axelrod (Chaney 1944; Axelrod 1950, 1958; Chaney and Axelrod 1959; Raven an Axelrod 1978) is based on fossil flora evidence and outlines three such floras for Nort America (fig. 3). In the southern half of the continent the Neotropical-Tertiary geoflora was dominated by broad-leaved evergreens. In the north, the Arcto-Tertiary geoflora was composed of a mixture of mixed temperate deciduous and evergreen species. In between these two and centered in the southern Rocky Mountains and adjacent present-day Mexico, the sclerophyllous and microphyllous Madro-Tertiary geoflora emerg (fig. 3). The Madro-Tertiary geoflora drew its constituent species from the stock of the other floras, but its plants of necessity became adapted to drier habitats.

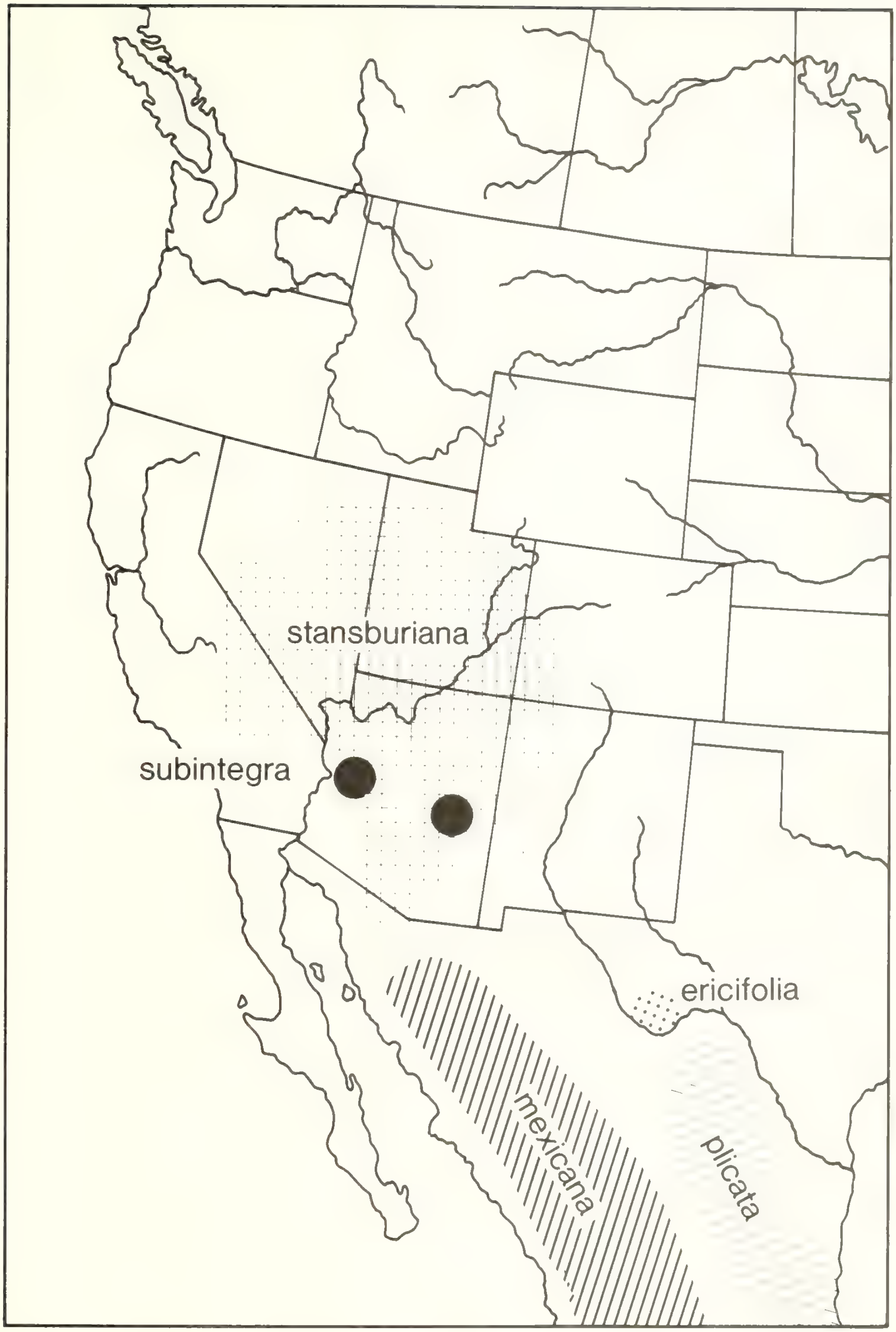

Figure 1.--Distribution of Cowania species (after Rydberg 1908-1918; Abrams 1944; Kearney and Peebles 1960; Vines 1960; Little 1976; Koehler and Smith 1981). Baker, Pinkava, and Righetti provided the location for the eastern population of *C. subintegra*.

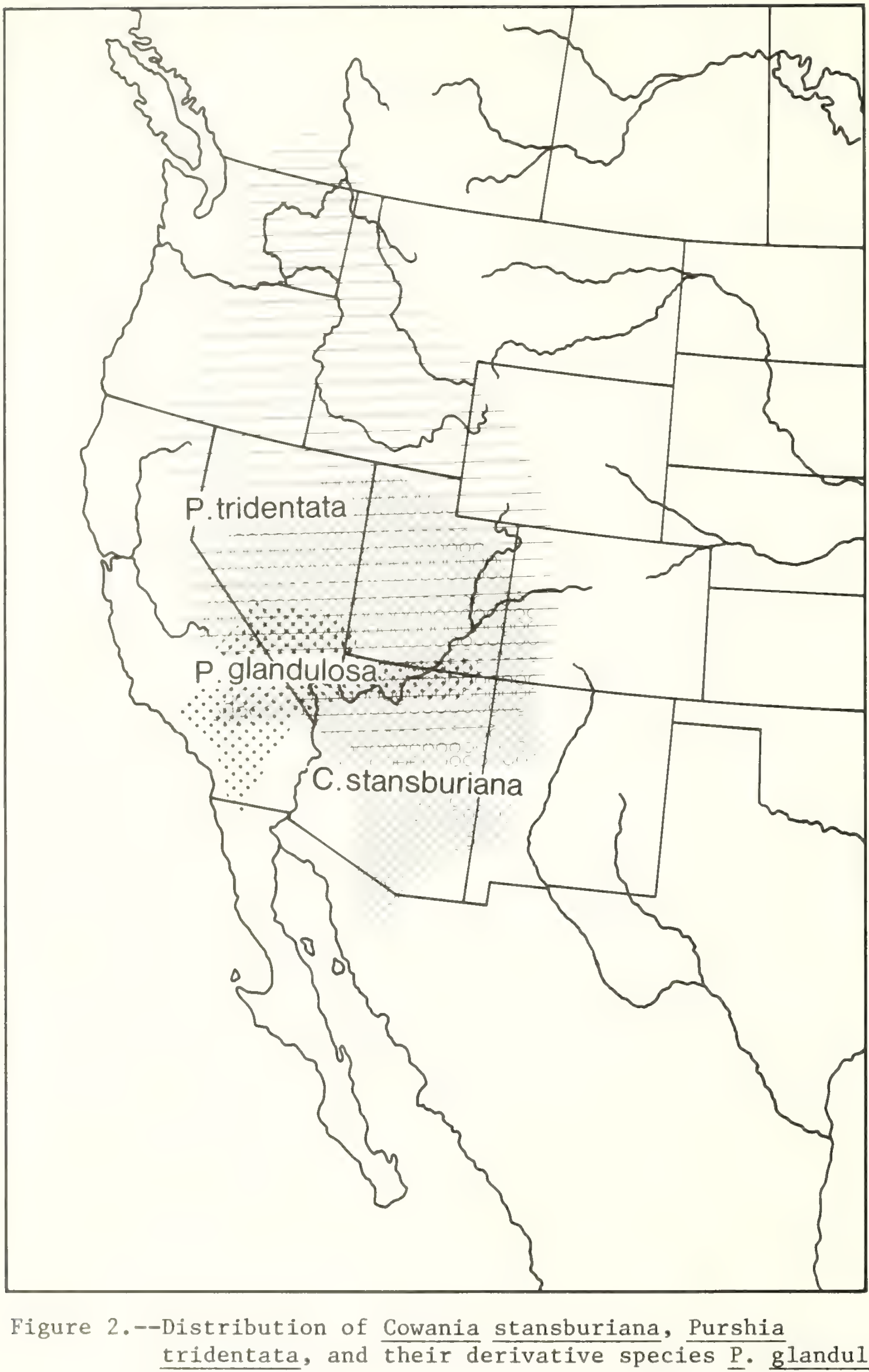

Figure 2.--Distribution of Cowania stansburiana, Purshia tridentata, and their derivative species P. glandulosa (after Stutz and Thomas 1964; Nord 1965; Koehler and Smith 1981).

Table 2.--Chromosome numbers of *Cowania*, *Purshia*, *Fallugia*, and hybrids

Taxa	Locale, collection number[1]	No. of plants sampled	*n*[2]	2*n*[3]
Cowania ericifolia Torr.	Dagger Flat, Big Bend National Park, Brewster Co., Texas, S&T, June 1978, 950 m.	1	9[4]	
Cowania mexicana D. Don.	Sombrerete, Zacatecas, Mexico, S, S&T, June 1978, 2 400 m.	2		18
Cowania plicata D. Don.	Iturbide, Nuevo Leon, Mexico, S, S&T, June 1978, 1 900 m.	3		18
Cowania stansburiana Torr.	Scipio, Millard Co., Utah	3		18
	Pine Valley, Washington Co., Utah, U8, 1 650 m.	2		18
	Kaibab Plateau, Coconino Co., Arizona, U15, 1 900 m.	3		18
	American Fork, Utah Co., Utah, U24, 1 550 m.	2		18
	Richfield, Sevier Co., Utah, U24, 1 700 m.	2		18
	Santaquin, Utah Co., Utah, U27, 1 550 m.	2		18
	Slaughter Creek, Washington Co., Utah, U35, 1 650 m.	2		18
	Fredonia, Coconino Co., Arizona, U37, 1 450 m.	2		18
	Prescott, Yavapai Co., Arizona, U38, 1 700 m.	2		18
	Canelo Hills, Santa Cruz Co., Arizona, U39, 1 700 m.	3		18
	Kaibab Plateau, Coconino Co., Arizona, U41, 1 900 m.	6		18
	Kyle Canyon, Clark Co., Nevada, U42, 2 150 m.	2		18
	Thoreau, McKinley Co., New Mexico, U43, 2 350 m.	7		18
	Conners Pass, White Pine Co., Nevada, U44, 700 m.	2		18

Table 2.--(Con.)

Taxa	Locale, collection number[1]	No. of plants sampled	n[2]	2n[3]
	Blanding, San Juan Co., Utah, U45, 1 900 m.	2		18
	Dave Valley, Lincoln Co., Nevada, U46, 1 950 m.	3		18
	Church Mtns., Millard Co., Utah, U49, 1 800 m.	2		18
	Willow Creek, Sevier Co., Utah, M&S 1348, 1 850 m.	1	9	
Cowania subintegra Kearney	Burro Creek, Mohave Co., Arizona, M 1344, 800 m.	3	9	
Purshia glandulosa Curran.	Jackson Springs, Washington Co., Utah, U2, 1 200 m.	2		18
	Caliente, Lincoln Co., Nevada, U7, 1 900 m.	2		18
	Pioche, Lincoln Co., Nevada, U8, 1 900 m.	1		18
	Ventura, Ventura Co., California, U13, 1 000 m.	4		18
	Oak Springs Summit, Lincoln., Nevada, U14, 1 900 m.	4		18
	Elbert Pass, Inyo Co., California, U15, 1 900 m.	2		18
Purshia tridentata (Pursh) DC.	Diamond Mtn., Uintah Co., Utah, U23, 2 300 m.	2		18
	Fairview, Sanpete Co., Utah, U26, 1 950 m.	1		18
	Mt. Pleasant, Sanpete Co., Utah, U31, 1 900 m.	4		18
	Janesville, Lassen Co., California, U29, 1 350 m.	4		18
	Fountain Green, Sanpete Co., Utah, U31, 1 850 m.	3		18
	Poontown Creek, Wasatch Co., Utah, U37, 2 500 m.	2		18

Table 2.--(Con.)

Taxa	Locale, collection number[1]	No. of plants sampled	n[2]	2n[3]
	Maybell, Moffat Co., Colorado, U47, 1 850 m.	2		18
	Mountain Dell, Salt Lake Co., Utah, U54, 1 700 m.	2		18
	Blackfoot, Bingham Co., Idaho, U57, 1 400 m.	2		18
	Pioche, Lincoln Co., Nevada, U64, 1 950 m.	2		18
	Vernal, Uintah Co., Utah, U74, 1 750 m.	2		18
	Bryce Canyon, Garfield Co., Utah, U79, 2 400 m.	2		18
	Fillmore, Millard Co., Utah, U82, 1 700 m.	2		18
	Boise, Ada Co., Idaho, U83, 1 600 m.	2		18
	Bishop, Inyo Co., California, U87, 1 850 m.	3		18
	Mono Lake, Mono Co., California, U90, 2 600 m.	2		18
	Neola, Duchesne Co., Utah, U91, 1 850 m.	2		18
	Preston, Franklin Co., Idaho, U95, 1 700 m.	2		18
	Long Valley Jct., Kane Co., Utah, U103, 2 300 m.	4		18
	Montrose, Montrose Co., Colorado, U104, 1 800 m.	1		18
	Silver City, Juab Co., Utah, U106, 1 900 m.	2		18
	Santaquin, Utah Co., Utah, U107, 1 600 m.	2		18
	Elko, Elko Co., Nevada, U114, 1 600 m.	1		18
	Reno, Washoe Co., Nevada, U116, 1 550 m.	2		18

Table 2.--(Con.)

Taxa	Locale, collection number[1]	No. of plants sampled	n[2]	2n[3]
	Silver City, Juab Co., Utah, U117, 1 900 m.	2		18
	Balm Creek, Baker Co., Oregon, U118, 1 100 m.	1		18
	Service Creek, Wheeler Co., Oregon, U119, 650 m.	2		18
	Izee, Grant Co., Oregon, U120, 1 350 m.	2		18
	Hat Rock State Park, Umatilla Co. Oregon, U121, 150 m.	2		18
	Oklahoma Gulch, Chelan Co., Washington, U123, 450 m.	2		18
	Hagerman Wildlife Management Area, Gooding Co., Idaho, U124, 900 m.	2		18
	Nahahum Canyon, Chelan Co., Washington, U125, 450 m.	2		18
	Wellsville Mtns., Box Elder Co., Utah, U126, 1 800 m.	2		18
	Cave Valley, Lincoln Co., Nevada, U127, 1 950 m.	3		18
	Blanding, San Juan Co., Utah, U128, 1 900 m.	3		18
	Diamond Range, Eureka Co., Nevada, U129, 2 200 m.	1		18
	Junction Valley, Cassia Co., Idaho, U130, 1 900 m.	2		18
	Deer Pasture, Millard Co., Utah, U134, 1 750 m.	2		18
	Canyon Mtns., Millard Co., Utah, U135, 1 800 m.	2		18
	Church Mtns., Millard Co., Utah, U136, 1 800 m.	2		18
	Church Mtns., Millard Co., Utah, U137, 1 800 m.	2		18
	Canyon Mtns., Millard Co., Utah, U138, 1 800 m.	2		18

Table 2.--(Con.)

Taxa	Locale, collection number[1]	No. of plants sampled	n[2]	2n[3]
	Lava Beds National Monument, Siskiyou Co., California, U139, 1 300 m.	2		18
	Lava Beds National Monument, Siskiyou Co., California, U140, 1 300 m.	1		18
	The Dalles, Wasco Co., Oregon, U143, 200 m.	2		18
	Okanogan Valley, Okanogan Co., Washington, B20, 300 m.	1		18
	Bell Rapids, Twin Falls Co., Idaho, B38, 950 m.	2		18
	Ritter, Grant Co., Oregon, B76, 950 m.	2		18
	Six Mile Lake, Harney Co., Oregon, B97, 1 390 m.	1		18
	Verdi, Washoe Co., Nevada, B100, 1 550 m.	2		18
	Point of Rocks, Sweetwater Co., Wyoming, B101, 2 050 m.	1		18
	Weed, Siskiyou Co., California, B103, 1 100 m.	2		18
	Soda Springs, Caribou Co., Idaho, B104, 1 900 m.	2		18
	Aztec, San Juan Co., New Mexico, B128, 1 830 m.	1		18
	Plains, Sanders Co., Montana, B178, 800 m.	2		18
	South Pass, Fremont Co., Wyoming, B183, 2 300 m.	2		18
	Hoback Junction, Teton Co., Wyoming, B185, 1 870 m.	2		18
	Dulce, Rio Arriba Co., New Mexico, NM503, 2 150 m.	1		18
(HYBRIDS) *C. stansburiana* X *P. tridentata*	Oakley, Cassia Co., Idaho, U3, 1 500 m.	2		18

Table 2.--(Con.)

Taxa	Locale, collection number[1]	No. of plants sampled	n[2]	2n[3]
	Junction Canyon, Cassia Co., Idaho, U3, 1 900 m.	2		18
	Wellsville Mtns., Box Elder Co., Utah, U4, 1 800 m.	1		18
	Payson Canyon, Utah Co., Utah, U41, 1 900 m.	5		18
	Nephi, Juab Co., Utah, U44, 1 700 m.	4		18
C. stansburiana X P. glandulosa	Snow Canyon, Washington Co., Utah, U5, 1 000 m.	2		18
P. tridentata X P. glandulosa	Benton Station, Mono Co., California, U5, 2 050 m.	1		18
Fallugia paradoxa (D. Don) Endl.	Hite, San Juan Co., Utah, S, May 1982, 1 050 m.	1	14	
	Willow Creek, Sevier Co., Utah, M&S 1347, 1 850 m.	1	14	
	Alpine, Brewster Co., Texas, Powell 3712, 1 400 m.	1	14	
	Pahcoon Springs Wash, Washington Co., Utah M 379, 1 050 m.	1	14	
	Pipe Springs, Mohave Co., Arizona, M 1345, 1 500 m.	2	14	
	Capitol Reef National Park, Wayne Co., Utah, M 1354, 1 650 m.	2	14	

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[1] Collection numbers: U = Seed accessions maintained by the Great Basin Experimental Station, Ephraim, Utah (USDA Forest Service, Intermountain Forest and Range Experiment Station and Utah Division of Wildlife Resources, cooperating); B = seed accessions maintained by Forestry Sciences Laboratory, USDA Forest Service, Intermountain Forest and Range Experiment Station, Boise, Idaho; M, M&S, S, S&T are authors' collections; NM = seed accessions maintained by Los Lunas Plant Materials Center, USDA Soil Conservation Service, Los Lunas, New Mexico; others are identified in Acknowledgements Section.

[2] n = gametic number from pollen mother cells.

[3] 2n = somatic number from root tip meristems.

[4] An additional univalent also observed.

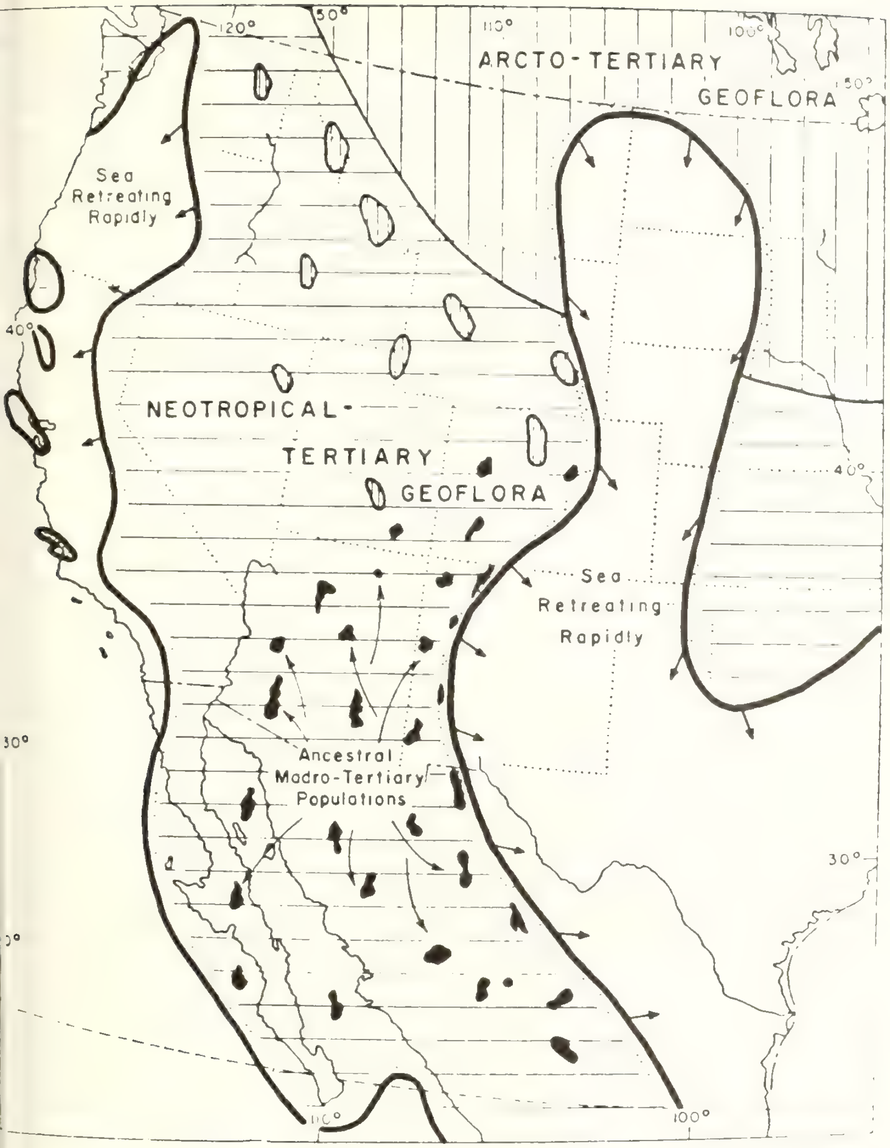

Figure 3.--Inferred distribution of ancestral Madro-Tertiary plants in pre-Eocene time (from Axelrod 1958).

Western Rosaceous Shrubs

We believe with Axelrod (1958) that rosaceous plant stocks available from the Arcto- and Neo-tropical geofloras became part of the more arid Madro-Tertiary geoflora. Apparently, these stocks evolved as new adaptations in the increasingly drier conditions of the Southwest. Axelrod (1950, 1958, 1977, personal communication) lists Amelanchier, Cercocarpus, Chamaebataria, Coleogyne, Cowania, Holodiscus, Lyonothamnus, Peraphyllum, Photinia, Prunus, Purshia, Rosa, and Vauquelinia as rosaceous genera occurring in the Madro-Tertiary geoflora. These genera represent all four rosaceous subfamilies (table 1).

The Madro-Tertiary geoflora is particularly rich in fossil records of Cercocarpus and Vauquelinia (Axelrod 1950, 1958). The records for Purshia and Cowania are more spotty. Purshia is recorded from the Pliocene some 10 million years ago (Axelrod 1958, personal communication). Cowania has not been recorded, although Axelrod (1977) suggested it was part of the mid-Eocene to Pliocene flora of 10 to 50 million years ago. An extinct fossil species of Fallugia is represented in the Creede, Colorado flora of 26.5 million years ago (Axelrod, personal communication).

Several rosaceous genera, all in the subfamiies Rosoideae and Spiraeoideae, have $\underline{x} = 9$ chromosomes, and Madro-Tertiary geoflora affinities (table 3). These species may be more closely related than placing them in separate subfamilies would indicate. Besides sharing the primitive $\underline{x} = 9$ chromosome number, both sets share growth habit similarities and are mostly endemic to western North America, and sclerophyllous or microphyllous. The high rates of endemism (10 of 13 genera) and monotypicism argue for a Madro-Tertiary geoflora connection within scattered pockets of habitat. The main exceptions are the circumboreal *Dryas*, *Physocarpus*, and *Spiraea*. The $\underline{x} = 9$ Rosoideae genera of table 3 may have more in common with Spiraeoideae than with $\underline{x} = 7$, mesic Rosoideae such as *Fragaria*, *Potentilla*, *Rosa*, *Rubus*, and *Sanguisorba*. For example, *Chamaebatia* of Rosoideae and its namesake *Chamaebatiaria* of Spiraeoideae resemble one another very closely in leaf form although they differ in fruit type and growth habit. The Rosoideae species of table 3 have close distributional, morphological, and actinomycete nodulation ties (Benson 1957; Klemmedson 1979). Nevertheless, we question the subfamilial distinctness of the genera listed in table 3 in light of their apparent affinities.

Table 3.-- Rosaceous shrubs with Madro-Tertiary geoflora affinities, $\underline{x} = 9^1$

Subfamily Rosoideae	No. of species	Distribution	Subfamily Spireaiodeae	No. of species	Distribution
Adenostoma	2	California and western Mexico	*Chamaebatiaria*[2]	2	Idaho, Utah, Nevada
Cercocarpus	7	Western North America including Mexico	*Holodiscus*[2]	14	Western North America including Mexico, Columbia
Chamaebatia[2]	2	California	*Kelseya*[2]	1	Idaho, Montana, Wyoming
Cowania	5	Western North America including Mexico	*Lutkea*	1	Northwestern North America
			Petrophytum[2]	5	Western North America
Dryas	4[3]	Circumboreal	*Physocarpus*[4]	6[3]	North America and Asia
Purshia	2	Western North America	*Spiraea*[4]	22[3]	Circumboreal

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[1] Shrubs of the subfamilies Rosoidae and Spireaiodeae with species west of the Mississippi River. Chromosome number, number of species, and species distribution information compiled from Rydberg (1908-1918), Martin (1950), Raven and others (1965), Taylor and Mulligan (1968), Bailey Hortorium Staff (1976), and tables 1 and 2.

[2] Based on new chromosome counts (Sanderson and McArthur, unpublished).

[3] Only North American species included.

[4] Also includes $\underline{x} = 7$ species (in the Asiatic portion of range).

Evolutionary History

The degree of relationship among taxa may be assessed, in part, by the fertility of hybrids between them. Reproductive isolation barriers are usually established by natural selection. They are, expectedly, most intense between species that have a long history of sympatric association (Stebbins 1974). Conversely weak isolation barriers are ordinarily indicative of recent evolutionary divergence or recent contacts between related, formerly allopatric species. We believe the weak isolation barriers between Cowania stansburiana and Purshia tridentata are indicative of their recent contact after a long separation. Although Cowania stansburiana differs in many attributes from Purshia tridentata, there is little restriction to their interbreeding.

An area including almost all of Utah and most of Nevada is an overlap zone for them (fig. 2), and hybrids are found at nearly every point of contact (Stutz and Thomas 1964). The only semblance of a reproductive isolation barrier is their partially disjunct flowering periods. Purshia tridentata usually flowers earlier than C. stansburiana, but in many places, C. stansburiana, growing on a south-facing or west-facing slope of a ravine, has its flowering period sufficiently advanced to overlap the retarded flowering period of P. tridentata growing on the adjacent north-facing or east-facing slopes. In such circumstances hybrids are abundant, mostly along the ridge tops separating the parental populations. The hybrids are highly fertile and often yield sizeable populations of hybrid segregants. More commonly, the hybrids backcross to the parents, providing genetic introgression from one species to the other. So common is introgressive hybridization that no population of bitterbrush yet examined in Utah is free from influence of earlier hybridization with cliffrose (Stutz and Thomas 1964; authors' unpublished observations). Introgression of bitterbrush into cliffrose is less common than introgression of cliffrose into bitterbrush, but that, too, occasionally happens. Such wholesale hybridization and subsequent introgression will undoubtedly provide numerous new adaptive products. Thus far only two have been detected: one to the south and one to the north of the overlap area (fig. 2). The southern adaptive derivative has been described as Purshia glandulosa. So recent is its origin that although it is uniform for those particular attributes that identify it as P. glandulosa, different populations are genetically distinct. This may reflect polyphyletic origins or chance fluctuations in occurrence of attributes not crucial for its establishment (Stutz and Thomas 1964). Koehler and Smith (1981) demonstrated that the flavonoid chemical complement of P. glandulosa is compatible with a hybrid ancestry.

North of Utah, beyond the geographic distribution of Cowania, some cliffrose characteristics are present in most bitterbrush populations (Stutz and Thomas 1964). A possible advantage to such introgressed populations may be a reduction in palatability to browsing animals. The magnitude of apparent introgression diminishes, as expected, with latitude, but even in a population in British Columbia a few plants bear stalked hypanthium glands, suggesting some influence of Cowania even at that northern latitude.

Because much of the overlap area of C. stansburiana and P. tridentata coincides with areas occupied by Pleistocene lakes and glaciers as recently as 12,000 years ago (Lindsay and Vickery 1967), the current distributions in the overlap areas are recent for both species. Their previous, probably disjunct, distribution allowed genetic divergence for many attributes, but provided little impetus for reproductive isolation.

Purshia and Cowania, while obviously related, differ in many attributes used in taxonomy (table 4): leaf size and shape, pubescence, glandulosity, time of flowering, number of stamens, number of carpels, deciduosity, and geographical distribution (Thomas 1957; Stutz and Thomas 1964). However, because some of the species hybridize in nature, yielding fertile progeny, some scientists (such as Cronquist, personal communication; Koehler and Smith 1981) thought it might be appropriate to combine them into one genus. The wisdom of such a rigid application of a single criterion for genus definition in the face of their numerous differences is questionable. Therefore, we prefer to retain them as separate genera. Other rosaceous genera (such as *Cydonia*, *Malus*, *Pyrus*, and *Sorbus*) also have intergeneric fertility but are maintained as distinct genera (Watkins 1976).

Table 4.--Morphological characteristics of species of *Cowania*, *Purshia*, and *Fallugia*

Species	Leaves									Flowers										Bark
Species	Length (mm)	Width (mm)	Lobes (#)	Sinus depth (0-3)	Dorsal pubesc. (0-3)	Revolute margin (0-3)	Gland abundance (0-3)	Gland formality (0-3)	Glands stalked (0-3)	Pedicel length (mm)	Pedicel glands (0-3)	Sepal length (mm)	Sepal glands (0-3)	Hypanth. angle*	Hypanth. pubesc. (0-3)	Hypanth. glands (0-3)	Glands stalked (0-3)	Achenes/hypanth. (#)		Color
COME	7	4	3	3	0	3	3	3	0	4	1	4	2	c	2	0	1	8		bronze
COST	7	4	5	3	0	2	3	2	0	5	3	6	2	f	0	3	2	6		gray
COER	6	1	0	-	0	3	0	-	-	3	3	2	3	f	3	3	3	14		gray
COSU	9	4	1	1	1	2	0	-	-	7	0	3	0	f	1	0	-	5		gray
COPL	11	6	6	1	0	1	v	v	v	6	3	6	3	f	2	3	3	12		brown
PUGL	6	3	3	2	0	3	3	2	0	4	0	5	0	f	1	0	0	2		gray
PUTR	10	7	3	2	3	0	0	0	0	1	0	3	0	f	1	0	0	1		gray
FAPA	10	6	3	3	1	2	0	0	0	13	0	6	0	c	1	0	0	55		yellow

* companulate = 40°, funnelform = 70°

Seven species of *Cowania* have been described: *C. alba* Goodding, *C. ericifolia* Torr., *C. mexicana* D. Don, *C. plicata* D. Don, *C. davidsonii* Rydberg, *C. stansburiana* Torr., *C. subintegra* Kearney. The single collection of *C. alba* is almost certainly *Purshia glandulosa* or a hybrid (Rydberg [1913, p. 416] notes that the collection of *C. alba* may be a hybrid between *C. stansburiana* and *P. glandulosa*--and, we have observed such hybrids in the general area of the only collection made for *C. alba*). *Cowania davidsonii* is one of the common variants of *C. stansburiana* (Kearney and Peebles 1960). As shown in table 4 and figures 1 and 4, the other five species have distinctive differences and distributions.

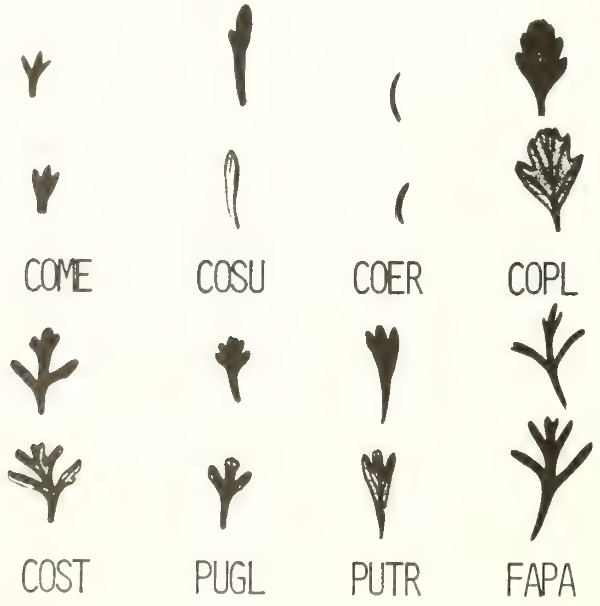

Figure 4.--Illustrated leaves of *Cowan* *Fallugia*, and *Purshia* speci (ca. X 1).

Cowania mexicana is found only on the slopes of the Sierra Madre Occidental in north-central Mexico. It is an erect, almost fastigate shrub 6.5 to 13 ft (2 to 4 m) high with short branches and conspicuously rusty-orange colored bark. The leaves are three-cleft with narrow entire lobes and deep sinuses (fig. 4) bearing nonstalked glands.

Cowania stansburiana grows northward from northern Mexico into California, Arizona, New Mexico, Colorado, Utah, and Nevada to about the 42° parallel. It usually grows in dry, well-drained shallow soils. It is usually 3 to 6.5 ft (1 to 2 m) tall, but some plants grow into small trees, 20 ft (6 m) or more in height. This species is frequently treated as a variety of *C. mexicana* (var. *stansburiana* [Torr.] Jeps.). We choose to accept it on the species level in a parallel treatment with the other *Cowania* taxa (table 4). It differs from *C. mexicana* in that *C. stansburiana* generally has more leaf lobes, a less revolute leaf margin, less glandular formality on leaves, a longer pedicel length, more pedicel glands, larger sepals, a more funnelform hypanthium angle, more stalked glands on flowers, and fewer achenes per hypanthium. The two taxa differ also in that *C. stansburiana* has glands on the hypanthium whereas *C. mexicana* has a pubescent hypanthium.

Cowania ericifolia has a restricted distribution in limestone rocks along the Rio Grande River in the Big Bend area of Texas. This short statured, straggling shrub has tiny needle-like leaves (fig. 4).

Cowania subintegra has been collected only near Burro Creek in west-central Arizona and near Bylas in southeastern Arizona. It grows in a calcareous shale with xerically adapted plants such as *Larrea tridentata* and *Cereus giganteus*. It is much like *C. ericifolia* in all respects except that many leaves have irregular and infrequent side lobes, and it is generally larger statured.

Cowania plicata is a very distinctive species, conspicuous because of its beautiful pink-crimson flowers. Its leaves are much broader than those of any other *Cowania* species (fig. 4) and are seasonally deciduous when grown in the Brigham Young University nursery in Utah. It grows in the Sierra Madre Oriental in northeastern Mexico in more mesic sites than do other *Cowania* species.

Fallugia paradoxa (D. Don) Endl. is monotypic and also shows minimal intraspecific variation. Although a common element in all of the deserts of southwestern North America (fig. 5), it is usually restricted to washes, seepage areas, and woodland margins, so it is somewhat more mesophytic than *Purshia glandulosa* and most species of *Cowania*. Superficially, because of its similarly lobed leaves and clusters of long, feather-tailed fruits, *Fallugia* appears to be closely related to *Cowania* (Benson 1957; Blauer and others 1975). However, its chromosome number (table 2, Baker, Pinkava, and Righetti unpublished) and floral characteristics (table 4) show that it is a distinctive genus. Furthermore, *Fallugia* also differs from *Cowania*, *Purshia*, *Dryas*, *Cercocarpus* and other $x = 9$ Rosideae shrubs (1) in not forming symbiotic actinomycete-induced nitrogen-fixing root nodules (Klemmedson 1979; Nelson in this proceedings; Righetti in this proceedings), and (2) in producing functionally dioecious plants (Blauer and others 1975; authors' personal observations). We are not certain if its primary alliances are with the $x = 9$ group of table 3 or with one of the $x = 7$ groups of table 1. Some of the $x = 7$ plants such as *Potentilla* have the dioecious habit of *Fallugia*. The curious case of the putative natural hybrids between *Cowania* and *Fallugia* (Blauer and others 1975) is apparently due to mutants of *C. stansburiana*. These plants have the $2n = 18$ chromosome number of *C. stansburiana* (authors' unpublished; Baker, Pinkava, and Righetti unpublished).

Purshia tridentata (Pursh) DC. is distributed from about the 37° N parallel northward into southern British Columbia, mostly on the western side of the Continental Divide (fig. 2). It differs from P. glandulosa and all of the Cowania species in being deciduous and having a much earlier flowering period (May-June). Other differences are listed in table 4.

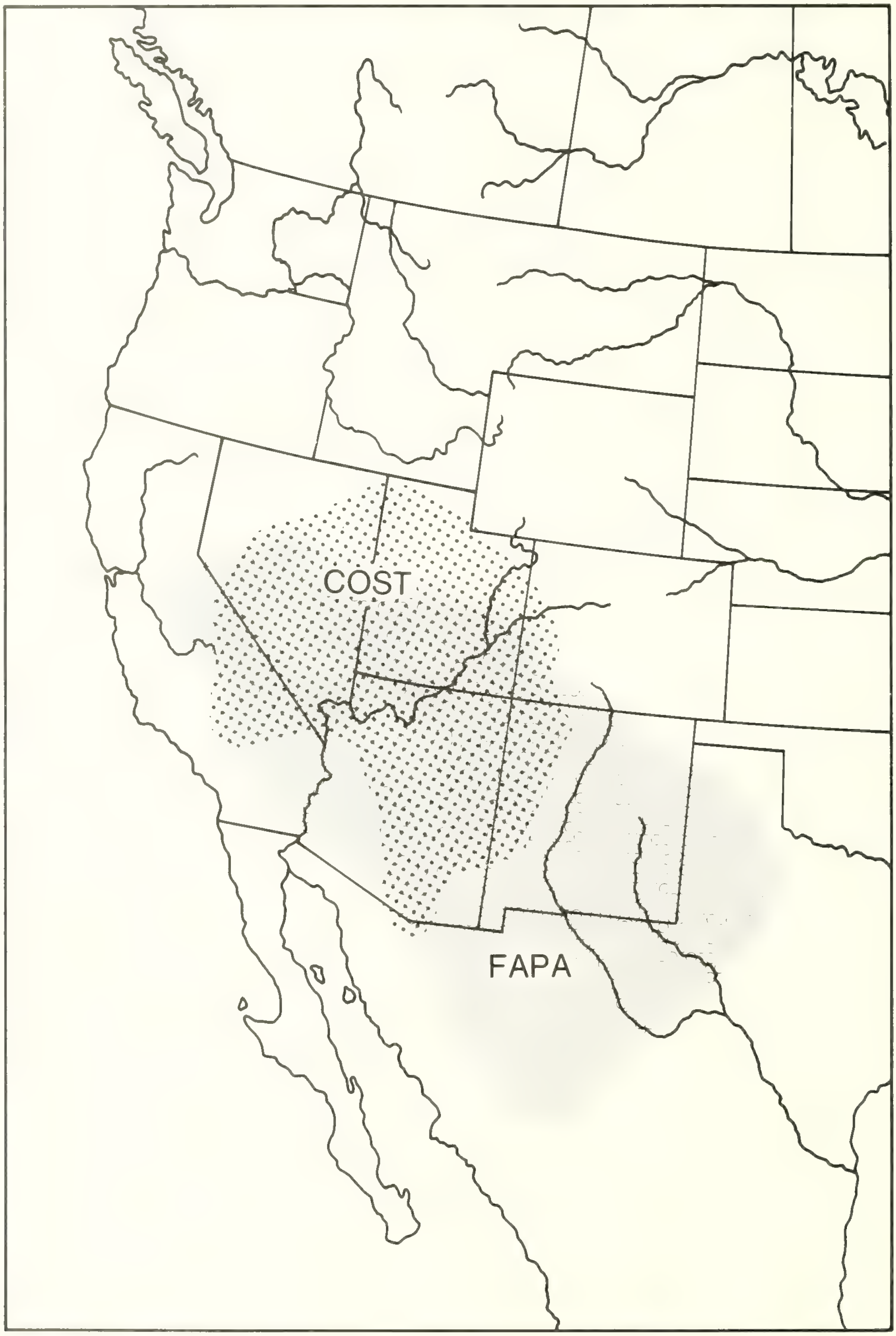

Figure 5.--Distribution of Cowania stansburiana (from fig. 2) and Fallugia paradoxa (after Kearney and Peebles 1960; Vines 1960).

Purshia glandulosa Curran is restricted to southern Utah, northern Arizona, southern Nevada, and southeastern California (fig. 2). Stutz and Thomas (1964) and Koehler and Smith (1981) report that it appears to be a hybrid derivative from *Cowania stansburiana* X *Purshia tridentata* parentage.

Cowania appears to be more ancient than *Purshia*. Furthermore, *Cowania*, has other attributes that make it attractive as ancestral stock. It has some apparent affinities with *Cercocarpus*, which has a demonstrated antiquity through an abundant fossil record (Axelrod 1950, 1958, 1977). We think it notable that *Cowania* and *Cercocarpus* both have long, plumose, persistent styles attached to their achenes. Furthermore, *Cowania* and *Cercocarpus* have a similar complement of isoenzymes, *more* similar, in fact, than do *Cowania* and *Purshia* (Leonard and others 1981). Their chromosomes are similar in size and staining behavior (authors' unpublished research). Both *Cercocarpus* and *Cowania* have higher numbers of species than the other Rosoideae of table 3; and they have better development in the south where the Madro-Tertiary geoflora underwent maximum development (figs. 1 and 3).

We make the proposal that *Cowania* is ancestral to *Purshia*. Its southern distribution, greater intraspecific differentiation, primitive traits (numerous flower parts and evergreen habit), and its apparent isoenzymatic and morphological kinship with the geologically widespread *Cercocarpus* make it a good candidate for primitive stock. *Cowania* appears to be among those desert shrubs that Axelrod (1958) proposed were derived from the Arcto- and Neo-tropical Tertiary flora following their emergence in the Sierra Madre region of Mexico during the Tertiary epoch. Its lobed, revolute-margined leaves appear to be adaptations that permitted it to accomodate the more xeric Madro-Tertiary environment and that have allowed it to continue as a desert shrub to the present. *Cowania mexicana* is probably most like the ancestral stock. From it, *C. ericifolia* was probably derived as a more extensive xerophyte bearing needle-like leaves that permitted it to occupy severely xeric sites. *Cowania stansburiana* apparently acquired multilobed leaves and numerous stalked glands that were necessary adaptations for spreading into the cooler drier climates to the north. *Cowania subintegra* with its subtle leaf-lobing may be an intermediate in the evolution of *C. ericifolia* or a separate spinoff in the line. Alternatively, it may be the product of hybridization between a previously more widespread *C. ericifolia* and *C. stansburiana*. Because *C. plicata* is so distinctive from the other *Cowania* species, it most likely diverged early in the evolution of the genus.

Purshia is also probably an early derivative from *Cowania* that subsequently evolved in isolation. Present contact between *Purshia* and *Cowania* is apparently very recent. An alternative hypothesis is that some ancestral stock gave rise to several related, but independent, entities from the evolving Madro-Tertiary flora, for example, *Cowania* and *Purshia* taxa. As mentioned above, *Purshia glandulosa* is clearly of recent origin (fig. 2).

Fallugia paradoxa was probably also a part of the Madro-Tertiary geoflora. It may have separated from *Cowania-Purshia* by chromosome number reduction or, more likely, it may be more closely related to $x = 7$ stock. In any case, it is now apparently genetically impoverished and narrowly niche-restricted.

Future evolution in this fascinating group of rosaceous plants will probably be most dramatic in the overlap areas of *Cowania* and *Purshia*. There, interhybridization is providing an unusually rich gene pool, probably much like that available during Tertiary when the merging of northern and southern species and the presence of moisture gradients provided similar extensive arrays of genetic combinations with resultant new adaptive themes.

CONCLUSIONS

Cowania, *Purshia*, and *Fallugia* are all derivatives of the rosaceous components of the Madro-Tertiary geoflora. *Cowania* with its more southern distribution, higher numbe of species, apparent antiquity, and affinity for *Cercocarpus* is probably most like the ancestral stock. *Cowania mexicana* may have been the springboard for the derivation of other species of *Cowania* and perhaps *Purshia*. *Fallugia*'s relationship to *Purshia* and *Cowania* remains unclear. Although it shares several morphological traits with *Cowania*, it has many distinctive differences including base chromosome number.

ACKNOWLEDGMENTS

This study was a cooperative endeavor of the USDA Forest Service, Intermountain Forest and Range Experiment Station, Brigham Young University, and the Utah Division of Wildlife Resources Pittman Robertson Project W-82-R, and the USDA Soil Conservation Service, Los Lunas and Tucson Plant Materials Centers. The National Park Service gave permission to collect plant materials in Big Bend and Capitol Reef National Parks.

PUBLICATIONS CITED

Abrams, L. Illustrated flora of the Pacific States, vol. 2. Palo Alto, CA: Stanford University Press; 1944. 635 p.

Alderfer, J. M. A taxonomic study of bitterbrush (*Purshia tridentata* [Pursh] DC) in Oregon. Portland, OR: Oregon State University; 1976. 197 p. M.S. Thesis.

Axelrod, D. I. Contributions to paleontology. VI. Evolution of desert vegetation in western North America. Carnegie Inst. Washing. Publ. 590: 215-306; 1950.

Axelrod, D. I. Evolution of Madro-Tertiary geoflora. Bot. Rev. 7: 433-509; 1958.

Axelrod, D. I. Outline of history of California vegetation. In: Barbour, M. G.; Major, J. eds. Terrestrial vegetation of California. New York, NY: John Wiley and Sons; 1977: 139-193.

Bailey Hortorium Staff, L. H. Hortus III. New York, NY: MacMillan Publishing Co.; 1976. 1290 p.

Baldwin, J. T., Jr. Chromosomes of *Spiraea* and certain other genera of Rosaceae. Rhodo 53: 203-206; 1951.

Benson, L. Plant classification. Boston, MA: D. C. Heath and Co.; 1957. 688 p.

Blauer, A. C.; Plummer, A. P.; McArthur, E. D.; Stevens, R.; Giunta, B. C. Characteristics and hybridization of important Intermountain shrubs. I. Rose family. Res. Pap. INT-169. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1975. 36 p.

Chaney, R. W. Introduction to Pliocene floras of California and Oregon. Carnegie Inst. Washing. Publ. 553: 1-19; 1944.

Chaney, R. W.; Axelrod, D. I. Miocene floras of the Columbia Basin. Carnegie Inst. Washing. Publ. 617; 1959. 237 p.

Cronquist, A. The evolution and classification of flowering plants. Boston, MA: Houghton Mifflin Co.; 1968. 396 p.

Darlington, D. C. Chromosome botany and the origins of cultivated plants. London: George Allen and Unwin., Ltd.; 1963. 231 p.

Darlington, D. C.; Moffett, A. A. A primary and secondary balance in Pyrus. J. Genet. 22: 129-151; 1930.

Federov, A. A. Chromosome numbers of flowering plants. Leningrad: Izdateyvo Nauk; 1969. 928 p.

Goldblatt, P. Cytotaxonomic studies in the tribe Quillajeae (Rosaceae). Ann. Missouri Bot. Gard. 63: 200-206.; 1976.

Goldblatt, P. ed. Index to plant chromosome numbers 1975-1978. Monographs in systematic botany from the Missouri Botanical Garden No. 5; St. Louis, MO: Missouri Botanical Garden; 1981. 553 p.

Johnson, A. M. Taxonomy of flowering plants. New York, NY: The Century Co.; 1931. 864 p.

Jones, S. B., Jr.; Luchsinger, A. E. Plant systematics. New York, NY: McGraw-Hill Book Co.; 1979. 388 p.

Kearney, T. H.; Peebles, R. H. Arizona flora 2nd ed., Berkeley, CA: University of California Press; 1960. 1085 p.

Klemmedson, J. O. Ecological importance of actinomycete-nodulated plants in the western United States. Bot. Gaz. (Suppl.) 140: S91-S96; 1979.

Koehler, D. L.; Smith, D. M. Hybridization between Cowania mexicana var. stansburiana and Purshia glandulosa (Rosaceae). Madrono. 28: 13-25; 1981.

Lawrence, H. M. Taxonomy of vascular plants. New York, NY: MacMillan Co.; 1951. 823 p.

Leonard, R. L.; McArthur, E. D.; Weber, D. J.; Wood, B. W. Electrophoresis of isoenzymes of 16 western shrubs: technique development. Great Basin Nat. 41: 377-388; 1981.

Lewis, W. H. Polyploidy in angiosperms: dicotyledons. In: Lewis, W. H. ed. Polyploidy, biological relevance. New York, NY: Plenum Press; 1980: 241-268.

Lindsay, D. W.; Vickery, R. K., Jr. Comparative evolution in Mimulus guttatus of the Bonneville Basin. Evolution. 21: 439-456; 1967.

Little, E. L., Jr. Atlas of United States trees. vol. 3. Minor western hardwoods. Misc. Publ. No. 1314. Washington, DC: U.S. Department of Agriculture, Forest Service, U.S. Government Printing Office; 1976. 309 p.

Martin, F. L. A revision of Cercocarpus. Brittonia. 7: 91-111; 1950.

Moore, R. J. ed. Index to plant chromosome numbers 1967-1971. Regnum vegtabile. vol. 90. Utrecht, Netherlands: International Bureau for Plant Taxonomy and Nomenclature. 1973. 539 p.

Moore, R. J. ed. Index to plant chromosome numbers 1972. Regnum vegtabile. vol. 91. Utrecht, Netherlands: International Bureau for Plant Taxonomy and Nomenclature. 1974. 108 p.

Moore, R. J. Index to plant chromosome numbers 1973-1974. Regnum vegtabile. vol. 96. Utrecht, Netherlands: International Bureau for Plant Taxonomy and Nomenclature. 1977. 257 p.

Nord, E. C. Autoecology of bitterbrush in California. Ecol. Monogr. 35: 307-334. 1965.

Ornduff, R. ed. Index to plant chromosome numbers 1956. Regnum vegtabile. vol. 50. Utrecht, Netherlands: International Bureau for Plant Taxonomy and Nomenclature; 1967. 128 p.

Raven, P. H. The bases of angiosperm phylogeny: cytology. Ann. Missouri Bot. Gard. 62: 724-764; 1975.

Raven, P. H.; Axelrod, D. I. Angiosperm biogeography and past continental movements. Ann. Missouri Bot. Gard. 61: 539-673; 1974.

Raven, P. H.; Axelrod, D. I. Origin and relationships of the California flora. Univ. Calif. Publ. Bot. 72: 1-134; 1978.

Raven, P. H.; Kyhos, D. W.; Hill, A. J. Chromosome numbers of spermatophytes, mostly Californian. Aliso. 6: 105-113; 1965.

Robertson, K. R. The genera of Rosaceae in the southeastern United States. J. Arnold Arboretum. 55: 303-332; 344-401, 611-662; 1974.

Rydberg, P. A. Rosaceae. North American Flora. 22: 239-533; 1908-1918.

Sanderson, S. C. Phylogenetic relationships of *Purshia tridentata* and *Cowania mexicana*. Provo, UT: Brigham Young University; 1969. 45 p. M.S. Thesis.

Sax, K. The origin of the Pomoideae. Amer. Soc. Hort. Sci. Proc. 30: 147-150; 1933.

Stebbins, G. L. Variation and evolution in plants. New York, NY: Columbia University Press; 1950. 643 p.

Stebbins, G. L. Flowering plants, evolution above the species level. Cambridge, MA: Belknap Press; Harvard University Press; 1974. 399 p.

Stutz, H. C.; Thomas, L. K. Hybridization and introgression in *Cowania* and *Purshia*. Evolution. 18: 183-195; 1964.

Taylor, R. L.; Mulligan, G. A. Flora of the Queen Charlotte Islands, part 2. Cytologic aspects of the vascular plants. Ottawa: Queen's Printer; 1968. 148 p.

Thomas, L. K. Introgression in *Purshia tridentata* (Pursh) DC. and *Cowania stansburiana* Torr. Provo, UT: Brigham Young University. 1957. 66 p. M.S. Thesis.

Vines, R. A. Trees, shrubs, and woody vines of the southwest. Austin, TX: University of Texas Press; 1960. 1104 p.

Watkins, R. Apple and pear, *Malus* and *Pyrus* spp. (Rosaceae). In: Simmonds, N. W., ed. Evolution of crop plants. London: Longman Group Ltd.; 1976: 247-250.

TAXONOMIC VARIATIONS OF BITTERBRUSH (PURSHIA TRIDENTATA) IN OREGON[1]

A. H. Winward and Jean Alderfer Findley[2]

ABSTRACT

Morphological and physiological characteristics of bitterbrush populations were examined in Oregon and northern California to determine which of the observed variations are genetic and which are environmental expressions. Four ecotypes were identified but extensive overlapping between populations was found. Specific characteristics studied indicated two separate trends for bitterbrush gene flow into Oregon.

INTRODUCTION

Bitterbrush (Purshia tridentata [Pursh] DC) is a palatable and nutritious shrub component of many western rangelands. Because of depletion over much of its range, considerable emphasis has been placed on its restoration during the past two decades. Many restoration attempts have met with either limited success or total failure. Although many factors have been explored to explain these failures, the possibility of genetic variation within this species often has been overlooked. Species such as bitterbrush that occupy broad environmental ranges have had ample opportunity for the development of such adaptive variations.

Many of us have observed a considerable amount of variation in bitterbrush. Height ranges from a low prostrate, layering form less than 1.6 ft (0.5 m) to large upright shrubs over 13 ft (4 m) tall. We have observed marked variation in leaf size, shape, color, and pubescence between areas as well as within a single population. Glandulation may occur on the hypanthia alone or on new leaders and leaves. Seed size, shape, and coloring varies markedly as does the hypanthium length. Growth form as influenced by leader and spur development likewise has shown distinct variation. In addition, we have observed major differences in the timing of such physiological functions as flowering and seed set over the shrub's geographic range.

Bitterbrush grows in association with a variety of vegetation types, including ponderosa pine, lodgepole pine, oak, juniper, or sagebrush. Sometimes it is a sole shrub dominant. Franklin and Dyrness (1973) recorded 18 recognized habitat types in Oregon of which bitterbrush was a major component.

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[1] Paper presented at Bitterbrush and Cliffrose Symposium, Salt Lake City, Utah, April 13-15, 1982.

[2] A.H. Winward, formerly Associate Professor, Oregon State University, is Regional Ecologist, USDA Forest Service at Ogden, Utah. Jean Alderfer Findley, formerly Research Graduate Assistant, Oregon State University, is Range Conservationist, Bureau of Land Management, Vale, Oregon.

Soil characteristics supporting bitterbrush vary widely. Parent material may be basaltic, rhyolitic, pumiceous, or sedimentary (Nord 1965). Generally, soils are coarse-textured, deep, and well drained; however, Driscoll (1964) reported stands of bitterbrush on fine-textured, stoney soils.

Several authors indicate that many of the differences observed between populations of bitterbrush may be genetically influenced (Nord 1959; Wagle and Vlamis 1961; Plummer and others 1968; Klemmedson and Ferguson 1969). We initiated this study to ascertain if bitterbrush is composed of distinct genetic groups that can be recognized and used to better understand management requirements for this forest and rangeland shrub. A more detailed discussion of pertinent information on the ecology and taxonomy of antelope bitterbrush can be found in Alderfer (1977) from which this publication is a part.

STUDY APPROACH

We selected 18 areas in eastern Oregon and two areas in northern California for field studies of specific bitterbrush populations. Populations selected for intensive study were chosen to represent major differences in growth form and morphology of bitterbrush plants, elevations, geographical range, dominant associated species, and physical environment. Every effort was made to select sites that presented reasonably undisturbed conditions and a minimum of utilization on bitterbrush plants.

At each site, measurements were made and characteristics studied for 20 vigorous, mature, seed-bearing individuals of the local bitterbrush population. We placed a vegetative sample from each plant in a paper bag for later chromatographic studies. A voucher specimen was likewise pressed for the 10 even-numbered plants from each site. As the season progressed, we collected seeds and their accompanying hypanthia from each of the 20 plants at each area.

Based on visual inspection and measurement of material from the pressed samples, ratings were developed and assigned for leaf glandulation, pubescence, length, width, lobing, general shape, and bark coloration. In an effort to evaluate growth form, leader growth was recorded as strongly upright or multidirectional. Layering, dense or open branching, and spur production also were rated.

We selected 450 well-filled seeds from 17 populations. These seeds were germinated and grown in a common greenhouse environment to help determine which characteristics were genetically fixed versus those that might represent environmental expressions. Percent emergence, cotyledon height, and leaf pubescence, glandulation, and shape were recorded for comparisons between different populations and between parent plants and their progeny.

Vegetative material from 10 samples at each of 15 sites was used for chromatographic tests. Root tips from the germination trials were used in the chromosomal studies. We used a cluster analysis technique in grouping populations of bitterbrush that had similar characteristics.

RESULTS

Data from the 20 study areas showed some clustering of kinds or races of bitterbrush, but a lot of overlapping occurred between populations. We found evidence of a gene flow pattern among populations into Oregon. There has been a pattern of gene exchange northward through Utah, down the Snake River in Idaho, and into northeastern Oregon. Our data suggest that another line of gene exchange has occurred westward from the Great Basin to the Cascade-Sierra Mountains and from there northward into Oregon and Washington. Major morphological differences between populations from these two areas of gene flow that showed in the cluster analysis are shown in table 1.

Table 1.--Major characteristics of two gene flow patterns found in Oregon.

	Idaho - Snake River	Cascade-Sierra
Leaves	Straight edge	Belled
Achenes	Long, indented	Filled
Hypanthia	Long	Short

In addition to these gene flow patterns, we found sufficient evidences to identify and describe four ecotypes of bitterbrush in Oregon. The pumice soils in the lodgepole pine region appear to have given rise to a local ecotype of bitterbrush characterized by small, dark green, heavily glandular plants that show a tendency toward prostrate growth form, layering, and lack of dense spur development (fig. 1).

In a similar and equally harsh but edaphically different environment at the top of Hart Mountain, another ecotype has developed. This ecotype is similar in growth form, color, layering, and glandulosity to the lodgepole pine ecotype, yet has certain distinctive features (fig. 1). Leaves at Hart Mountain are more belled and have shallower lobes, a striking white bark, and yellowish rather than redish glands. Seed set and shatter occurs in late summer versus early summer for the lodgepole ecotype.

We found two additional ecotypes representing tall plants with long, large leaves and heavy seeds, one in the Janesville area of northern California and the other along portions of the Snake River drainages in north eastern Oregon (fig. 2). Both locations have long growing seasons and deep soil, in contrast to the rather harsh environmental conditions that gave rise to the Hart Mountain and lodgepole pine ecotypes. These two tall ecotypes actually showed more dissimilarity than the low, layering ecotypes. Differences were particularly evident in the hypanthium length, achene shape and markings, glands on the hypanthia, leaf pubescence, and a distinct point on the outer leaf lobes (table 1).

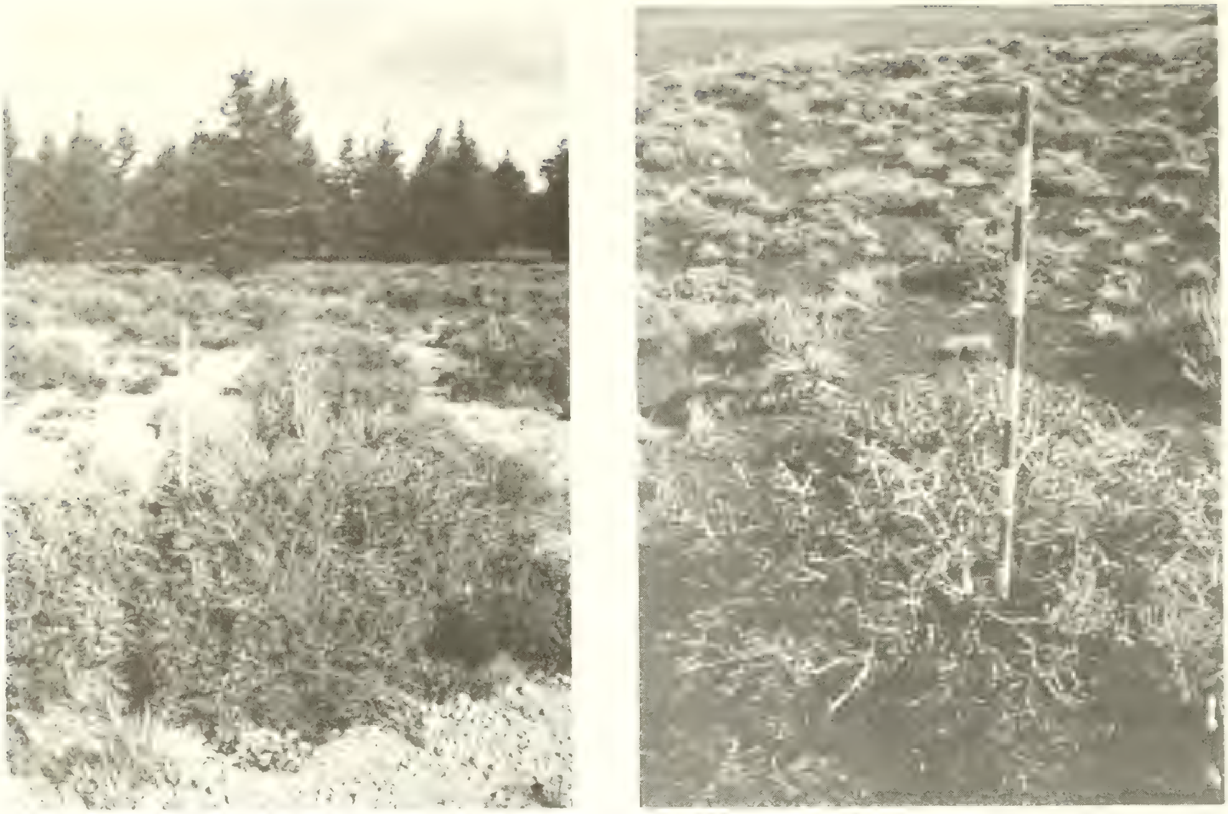

Figure 1.--Examples of low, layering ecotypes: Left - Lodgepole/Pumice, and right - Hart Mountain.

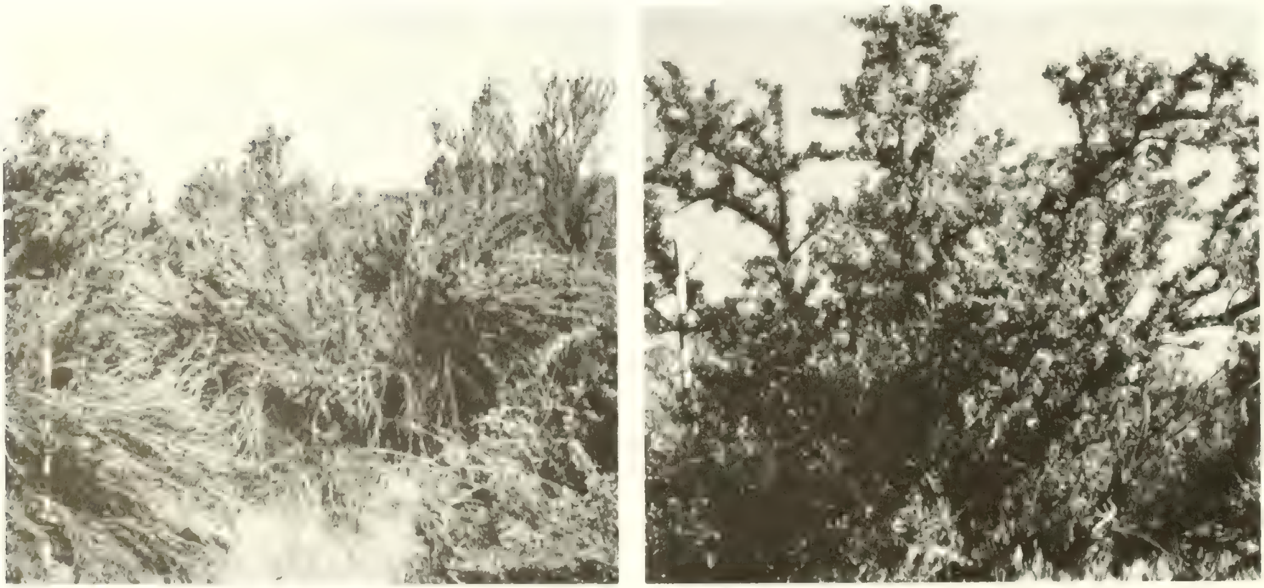

Figure 2.--Examples of tall, massive ecotypes: Left - Janesville, and right - Snake River.

However, in support of the ecotype concept for these four races, all retained many of their characteristics under common conditions in the greenhouse (fig. 3). Although morphology was variable within and between populations of these ecotypes, silhouettes in figure 4 demonstrate the general leaf shapes of each of the four Oregon ecotypes. These silhouettes also demonstrate that leaf morphology varies depending on its position on the plant. This characteristic can be useful in better understanding bitterbrush taxonomy, and it may be an important management feature. For example, size of overwintering leaves varies considerably among ecotypes, which, in turn, can influence the winter nutrient status of bitterbrush.

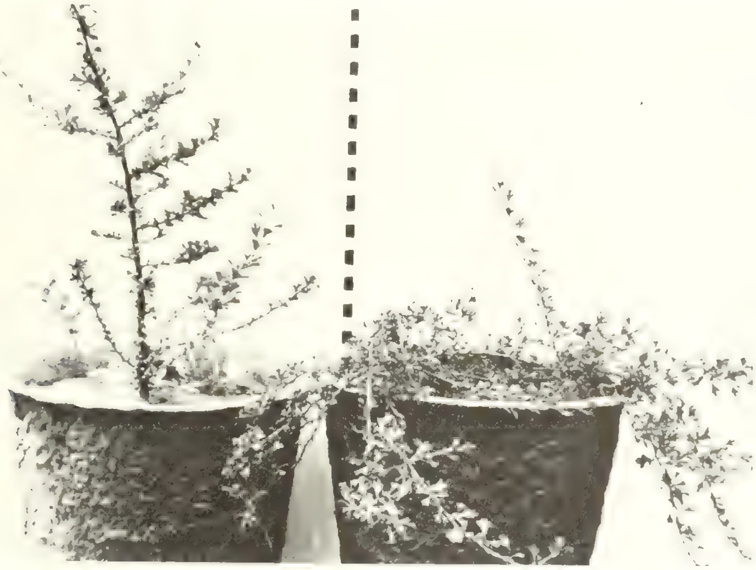

Figure 3.--Plants showing upright (left) and recumbent (right) growth form for plants grown in the greenhouse. Left - Snake River ecotype, and right - Lodgepole/Pumice ecotype.

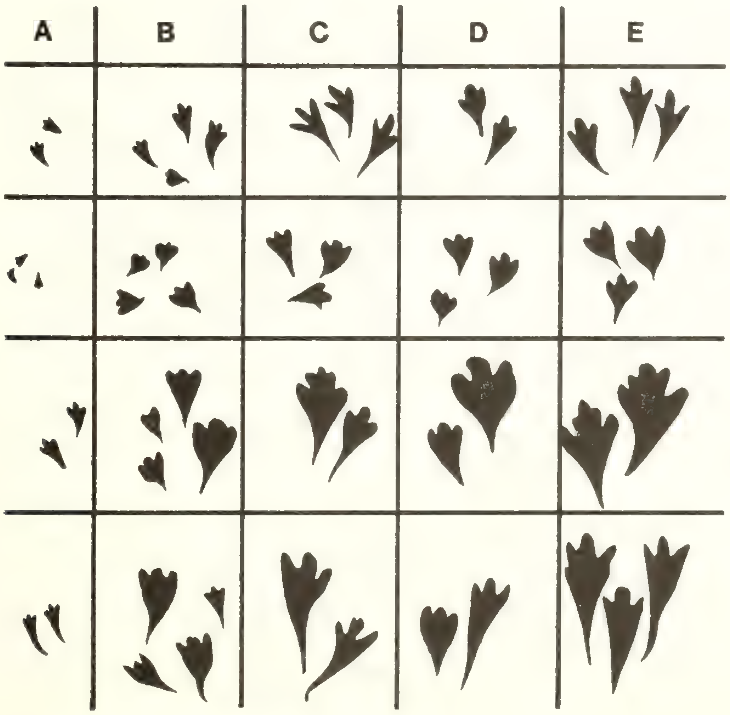

Figure 4.--Variation in leaf characteristics for the four Oregon ecotypes. Kind of leaf and/or position are as follows: A = overwintering; B = outside spur; C = inside spur; D = first leader; E = second and subsequent leader

The remainder of the bitterbrush populations studied appeared to represent merging of characteristics from two or more of the four described ecotypes.

Chromosome counts showed all bitterbrush populations studied were diploid (2n = 18). No evidence of polyploidy was found. In the chromatographic studies, we could not find adequate correlation between the flavanoid and phenolic spots and morphological characteristics, nor geographical distribution of bitterbrush. We did find four spots common to cliffrose (Cowania stansburiana Torr.) in sampling desert bitterbrush (P. glandulosa) obtained from southern California. This supports statements by other authors regarding introgression of cliffrose and desert bitterbrush (Nord 1965). These four spots were found only sporadically in antelope bitterbrush; yet, they likewise indicate that some populations of antelope bitterbrush may show introgression with cliffrose. However, no distributional pattern could be discerned for plants or populations containing these spots.

CONCLUSIONS

Because bitterbrush has the characteristic to outbreed (readily crosses with other bitterbrush plants in the vicinity) and because it is known to hybridize with cliffrose, it contains a diverse genetic reserve so that, in total, the species is well adapted to a number of diverse environments. This has been both an advantage and disadvantage to managers. The advantage is the wide diversity of material to choose from when selecting sources of bitterbrush for specific sites or uses. The disadvantage is that it is difficult to match the best genetic material to our particular needs. For managers contemplating bitterbrush seeding projects, seed source remains critically important. Indiscriminate choice of seeds may be responsible for our past and present seeding failures. We need to study tolerance ranges of all races of bitterbrush so we can better predict their limitations. For example, the two low layering ecotypes may be highly adapted for establishment on certain harsh sites. However, it would appear the Hart Mountain ecotype may be more successful on harsh, shallow soil sites in higher mountainous areas of the Western United States because it is adapted to the shorter frost-free growing season at these elevations.

A relationship was observed between taller plants and frost-free growing season. Seeds from the tall ecotypes may produce seedlings unable to survive where severe frosts occur frequently. Failure of some of our past seeding is likely related to selection of nonfrost tolerant ecotypes. If local or on-site seed is not available, we recommend that associated vegetation, soil type, and frost-free growing season of the seed source be matched as nearly as possible to the site selected for seeding.

Based on our study of the four ecotypes, we also recommend that the presoak treatment in thiourea to break bitterbrush seed dormancy be extended from the currently recommended 5 min. treatment to a 15-20 min. treatmemt. We found that a 5 min. soak was not adequate for all ecotypes studied, while the 15-20 min. soak broke dormancy in all ecotypes. A longer 20 min. soak is not recommended because it may damage the radicle of some types.

As we continue to understand more about the genetic nature of bitterbrush, we will most likely increase our ability to manage this complex and interesting shrub.

PUBLICATIONS CITED

Alderfer, Jean Marie. A taxonomic study of bitterbrush (Purshia tridentata [Pursh] DC) in Oregon. Corvallis, Or: Oregon State University; 1977. 197 p. Masters Thesis.

Driscoll, Richard S. Vegetation-soil units in the central Oregon juniper zone. Res. Pap. PNW-19. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1964. 60 p.

Franklin, J.F.; Dryness, C.T. Vegetation of Oregon and Washington. Res. Pap. PNW-80, Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1973. 216 p.

Klemmedson, J.O.; Ferguson, R.B. Response of bitterbrush seedlings to nitrogen and moisture on a granitic soil. Proc. Soil Science Society of America 33:962-966. 1969.

Nord, Eamor C. Bitterbrush ecology--some recent findings. Res. Note 148. Berkeley, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station; 1959. 8 p.

Nord, Eamor C. Autecology of bitterbrush in California. Ecol. Monog. 35:307-334. 1965.

Plummer, A. Perry; Christensen, Donald R.; Monsen, Stephen B. Restoring big game range in Utah. Publ. No. 68-3. Salt Lake City, UT: Utah State Division of Fish and Game; 1968. 183 p.

Wagle, R.F.; Vlamis, J. Nutrient deficiencies in tow bitterbrush soils. Ecology 42:745-752. 1961.

BITTERBRUSH DISTRIBUTION AND HABITAT CLASSIFICATION ON THE BOISE NATIONAL FOREST[1]

Ronald K. Tew[2]

ABSTRACT

On the Boise National Forest, bitterbrush occurs most abundantly between 3,200 and 4,500 ft (975 and 1371 m) elevation. Hot south-facing slopes have the greatest tendency to support bitterbrush at all elevations. On sites having deep soils, plants are tall and treelike, but they are prostrate on many of the harsher sites.

INTRODUCTION

Numerous classification and stratification schemes could be used to inventory natural resources. Most are used to identify units of land that have unique resource values or constraints. In mapping, some characteristics often used as a basis include soils, vegetation, landform, geology, and climate. These variables may be mapped independently or as an integrated system. The approach that has been followed here is an integrated inventory with emphasis on landform, geology, vegetation, and climate. Soil is given emphasis at lower levels in the inventory system.

Whatever approach is used, a base map is generally prepared that provides a common land resource frame of reference for various disciplines to relate to in land management planning. Advantages to such an approach from the standpoint of bitterbrush management include: (1) predictive capabilities are improved in a homogeneous setting; (2) there is a basis for extrapolation of information; (3) sampling variation is reduced when resource inventories are done in a relatively homogeneous environment; (4) there is a recognized unit of land for describing the location of available resources; and (5) there generally is better interdisciplinary communication when a common land base has been established as a reference point.

FOREST STRATIFICATION

The concepts of land systems inventory presented by Wertz and Arnold (1972), with modifications proposed by Bailey (1980), provided the framework for land stratification on the Boise National Forest. Bailey's ecoregion concept provided the first broad level of stratification using climate and potential vegetation as variables. Within ecoregions, "zones" were established by superimposing subsections as defined by Arnold (1975). These zones were distinguished on the basis of landform, climate, and geologic structure. Zones were divided into "landtype associations" as defined by Wertz and Arnold (1972).

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[1] Paper presented at the Bitterbrush and Cliffrose Symposium in Salt Lake City, Utah, April 13-15, 1982.

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All or portions of 21 zones were established to cover about 3 million acres (1.2 million ha) in the Boise National Forest. The general location and the approach used is shown in figure 1.

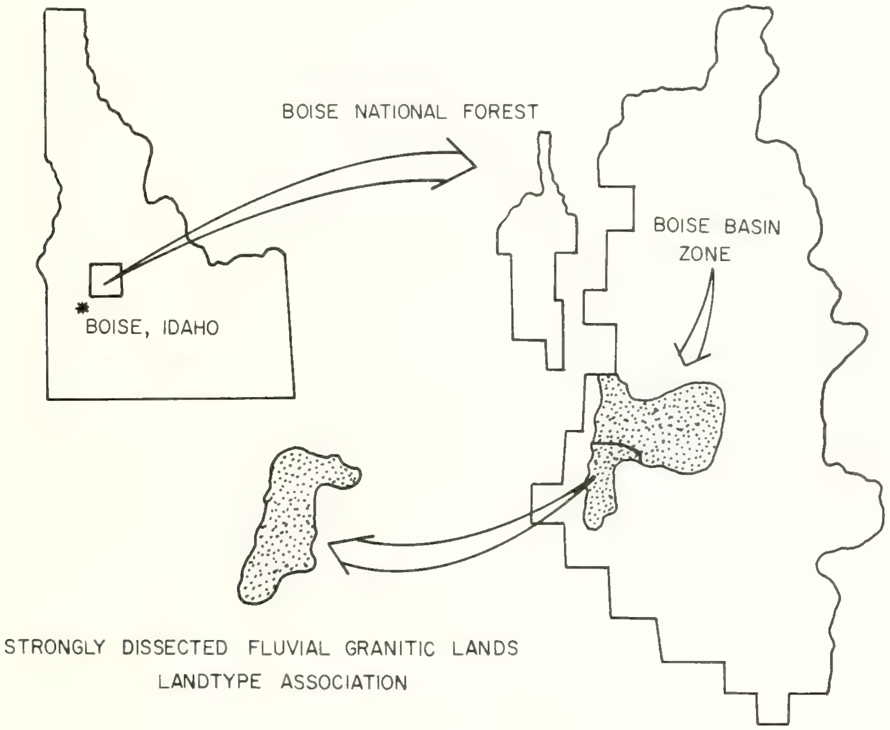
BOISE NATIONAL FOREST
BOISE BASIN ZONE
BOISE, IDAHO
STRONGLY DISSECTED FLUVIAL GRANITIC LANDS LANDTYPE ASSOCIATION

Figure 1.--General location of the Boise National Forest with an example of land stratification.

Generally three to five landtype associations were recognized in each zone. These divisions were based primarily on landform, geology, vegetation, and climatic factors. Slope forming factors, such as glacial and fluvial action, as well as water handling characteristics of the slopes, were also considered.

GEOLOGY AND SOILS

About 85 percent of the Boise National Forest lands are within the Idaho batholith where granitic parent materials dominate. The soils are sandy and often shallow to moderately deep, over fractured, and/or decomposed granite.

A few basalt flows and silicic volcanic lands occur on the southern end of the Forest where deeply cut canyons overshadow the streams. The west and central portion of the Forest has a limited acreage of structurally controlled basalt lands with long, steep, west-facing dip slopes. In these areas, soils are often shallow, cobbly, clay loams over hard bedrock. These differences in soil and geology have been taken into account in the Forest stratification process.

CLIMATE AND ELEVATION

The average annual precipitation ranges from 14 inches (36 cm) on the southern end of the Forest to a high of 70 inches (178 cm) on the northern end. The precipitation is closely tied to elevation ranging from 3,200 ft (975 m) to approximately 10,000 ft (3046 m). There is also a close link to latitude, with more moisture in the northern latitudes. Rain shadow effects are apparent throughout the area.

Summers are hot and dry with little moisture falling on the lower elevation slopes between June and September. Temperatures exceeding 90° F (32° C) are common during several weeks in July and August. The combination of high temperatures and relatively low rainfall makes conditions for plant growth quite severe. Even so, many species are able to adapt to the harsh climatic conditions by sending roots deep into the fractured granitic materials.

PLANT/HABITAT TYPE CHARACTERIZATION

Hironaka and Fosberg (1981) are cited as the authorities on habitat types. Scientific names follow Holmgren and Reveal (1966) except where tentative subspecies of big sagebrush (Artemisia tridentata ssp. spiciformis and Artemisia tridentata ssp. xericensis) are identified. In these cases, concepts presented by Hironaka and Fosberg (1981) are used.

BITTERBRUSH DISTRIBUTION

Purshia tridentata (Pursh) DC., (bitterbrush), occurs most abundantly between 3,200 and 4,500 ft (975 and 1371 m) elevation, although a few sites may have plants above 5,500 ft (1676 m). Hot south-facing slopes have the greatest tendency to support bitterbrush at all elevations, even though annual precipitation on sites supporting bitterbrush ranges from 14 to 35 inches (36 to 89 cm).

Bitterbrush habitat types occur on both volcanic and granitic parent materials. In each case, bitterbrush dominates only the relatively harsh sites, but dense stands of bitterbrush may occur on productive sagebrush habitat types as well.

On the southern end of the Forest, the Basalt Plains and Canyons landtype association contains several Artemisia arbuscula Nutt. var. arbuscula (low sagebrush) habitat types. Shallow, rocky, clay loam soils that are saturated in the spring for short periods are prevalent. Bitterbrush is not common on these habitat types. Only a few decadent plants are scattered along the edges of the communities. However, it is common to see several sagebrush habitat types mixed together, and the total landscape may have considerable bitterbrush present in a mosaic pattern.

Artemisia tridentata Nutt. ssp. vaseyana (Rydb.) Beetle/Agropyron spicatum (Pursh) Scribn. & Smith var. spicatum, (mountain big sagebrush/bluebunch wheatgrass) is by far the most common habitat type. Bitterbrush is a regular component on most of these sites. Because this habitat type covers the entire elevational range of bitterbrush on the Forest, there are many soil types involved. As a result, bitterbrush density, production, plant size, and shape varies considerably. Landform can vary from gently rolling hills to long, very steep slopes.

The Artemisia tridentata Nutt. ssp. vaseyana (Rydb.) Beetle/Festuca idahoensis Elmer (mountain big sagebrush/Idaho fescue) habitat type is most prevalent on steep north-facing slopes. Bitterbrush is generally sparse on these sites, although some plants are present.

The Artemisia tridentata Nutt. ssp. tridentata (basin big sagebrush) habitat types occur primarily at the lower elevations on depositional soils. These sites are productive because of the deep soils, and in some cases moisture is received from adjacent slopes. There are some areas where dense stands of bitterbrush occur and plants exceed 6 to 8 ft (1.8 to 2.4 m) in height. When this condition occurs, the sagebrush is generally sparse.

The Artemisia tridentata ssp. xericensis (x big sagebrush) habitat types are common between 3,500 and 5,000 ft (1066 and 1676 m) elevation. These sites are usually highly productive and have considerable species diversity. It is also common to find basin big sagebrush and mountain sagebrush on these sites. Bitterbrush does well and again produces large plants. Bitterbrush may be relatively abundant or somewhat sparse.

The Artemisia tridentata ssp. spiciformis/Bromus carinatus Hook. & Arn. (alpine big sagebrush/California brome) habitat type occurs on the high elevation glaciated landtype associations. Because of the high elevations and cool, moist climatic conditions, it is uncommon to find bitterbrush growing on these sites.

Zones and landtype associations occurring in the central portion of the Forest have vast amounts of bitterbrush growing on the granitic materials. Bitterbrush habitat types are common, especially on hot south-facing slopes. The slopes are generally very steep and considerable natural erosion is evident. Soils are shallow and have coarse textures. Plants are often prostrate with an abundance of dead wood present.

There are some unique slopes that are dominantly native grasslands. The slopes are long, very steep, and have a smooth graded appearance. Soils are shallow over granitic bedrock. On these slopes, bitterbrush may be observed in a few places. The plants usually follow the rock fracture lines across the slopes. Here the plants can anchor their roots deeply into the substratum.

The zone immediately north of Boise is unusual in that it is the only place on the Forest where vast stands of Aristida longiseta Steud. var. longiseta (red three-awn) are present. Some of the finer textured soils are in this zone. Here bitterbrush occurs most densely along a belt between 3,200 and 4,500 ft (975 and 1371 m) elevation. Several sagebrush species are commonly associated with the bitterbrush.

Along the west-central portion of the Forest, structurally controlled basalt lands with long, steep west-facing slopes are present. Here soils are shallow clay loams with a high coarse fragment content. Bitterbrush habitat types are common within this zone, and sagebrush habitat types are somewhat limited in extent. Red three-awn, which is so common a few miles to the east, becomes sparse on the volcanic materials.

On the high elevation glaciated landtype associations and on the high elevation meadows that occupy large acreages on the northern portion of the Forest, bitterbrush distribution becomes very limited. Precipitation is high, reaching 70 inches (178 cm) per year in some areas. Temperatures are cool and the growing season is short. Much of the land in this vicinity is covered with dense stands of timber, thus eliminating bitterbrush, except in a few scattered ponderosa pine stands at the lower elevations.

MANAGEMENT IMPLICATIONS

Because several big-game winter ranges occur on the Boise National Forest, it is essential that adequate food sources be maintained on key habitats. It is important to maintain a diversity of plants as well as an abundance of major food supplies. To meet these demands, the Forest has been actively engaged in a bitterbrush planting and management program. Several factors have influenced program results: (1) gopher activity is intense on some landtypes where soils are deep; (2) seeds or seedlings adapted to specific habitat types have not always been as carefully selected as they should have been (that is, seed from large treelike bitterbrush plants on basin big sagebrush habitat types may not do as well on shallow soils where prostrate bitterbrush plants are commonly found); (3) summers are hot and dry, which creates a tremendous moisture stress on new plants during their first growing season; (4) it has not always been recognized that bitterbrush plants perform best on sites where roots can easily penetrate the soil or where fractures in the parent material provide channels that roots can anchor into, nor that bitterbrush competes well on the harsh dry sites because it is capable of sending roots into the fractured granitic materials; and (5) bitterbrush plants are often killed by fires that commonly occur during the hot summer months, which needs to be accounted for in any economic consideration.

CONCLUSIONS

Zones and landtype associations are units of land that have unique qualities from the standpoint of resource production potentials, management constraints, and opportunities for improvement. Only two broad levels of land stratification have been addressed here for the Boise National Forest as a reference framework. However, more detailed inventories have identified landtypes and range types. At both levels of stratification, bitterbrush distribution, plant height, shape, and production can be predicted.

By recognizing site potentials, constraints, and opportunities at various levels of land stratification, better land management prescriptions can be developed in future planning cycles. Communication between specialists can also be improved because specialists relate to common units of land that have been well described. The result should be more efficient bitterbrush management in the years ahead.

PUBLICATIONS CITED

Arnold, John F. The Idaho batholith--A source of information. Ogden, UT: U.S. Department of Agriculture, Forest Service; 1975. 290 p.

Bailey, Robert G. Descriptions of the ecoregions of the United States. Misc. Publ. 1391. Ogden, UT: U.S. Department of Agriculture, Forest Service; 1980. 77 p.

Hironaka, M.; Fosberg, M.A. Nonforest habitat types of southern Idaho - workshop II. Interim report. Moscow, ID: Forest, Wildlife, and Range Expt. Sta./U.S. Department of Agriculture, Forest Service; 1981. 89 p.

Holmgren, Arthur H.; Reveal, James L. Checklist of the vascular plants of the Intermountain Region. Res. paper INT-32. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1966. 160 p.

Wertz, William A.; Arnold, John F. Land systems inventory. Ogden, UT: U.S. Department of Agriculture, Forest Service; 1972. 12 p.

Section 2. Growth Performance, Phenology, and Physiology

PERFORMANCE COMPARISON AMONG POPULATIONS OF BITTERBRUSH, CLIFFROSE, AND BITTERBRUSH-CLIFFROSE CROSSES ON STUDY SITES THROUGHOUT UTAH[1]

James N. Davis[2]

ABSTRACT

Since the late 1950s, 259 accessions of bitterbrush, cliffrose, and bitterbrush-cliffrose crosses have been grown on many diverse pinyon-juniper sites throughout Utah. Extensive plantings have helped to determine where each accession performs best. Some accessions perform well at many locations. Managers can use these accessions to meet a wide variety of site characteristics. Most areas of the West are represented by the 259 accessions.

INTRODUCTION

Bitterbrush (Purshia tridentata) [Pursh] DC) and Cliffrose (Cowania mexicana var. stansburiana [Torr.] Jeps.), because of their abundance and importance in the Western United States, have been the subject of many studies, most of them directed toward bitterbrush. Studies on bitterbrush commonly involve nutrition, palatability, germination, planting methods, genetics, general ecology, management, production, nitrogen fixation, and the effects of fire, cold, soil, and moisture relationships.

Most research has only hinted at the possible usefulness of the abundant genetic variation within or between populations of bitterbrush and cliffrose. To meet the needs of a wide variety of site and management problems, selection of divergent natural forms should be pursued.

Antelope bitterbrush in Idaho was found to resprout readily following fire and clipping trials (Blaisdell and Meuggler 1956). After such treatments were initiated on unburned and earlier (1939) burned-over areas there was less than 50 percent sprouting on the unburned areas as compared to 75 percent sprouting on the previously (1939) burned site for individuals that sprout after fire. Further selection had occurred on the previously burned site for individuals that sprout after fire. Hormay (1943) reported that hundreds of thousands of acres of bitterbrush in California had been destroyed by fire, and that only two occurrences of sprouting had been observed. Driscol (1963) listed percent sprouting of bitterbrush on 13 burned areas throughout central Oregon. Percent sprouting ranged from 1 to 80 percent. He noted that there appeared to be little relationship between intensity of the burn and the degree of sprouting. Nord (1965) found resprouting of antelope bitterbrush after burning or cutting to occur infrequently in California, while desert bitterbrush (Purshia glandulosa Curran) resprouted frequently. Billings (1952) stated that bitterbrush in the western Great Basin is permanently lost by fire due to the fact that it rarely sprouts. Within some areas of critical big-game range, the reoccurring incidences of fire would be very detrimental. Therefore, the ability of bitterbrush to resprout after fire would be an excellent heritable characteristic to have.

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Many observers have noted other variable characteristics within populations of bitterbrush: seed dormancy (Nord 1965); leaf color (Hormay 1943; Stanton 1959), growth form and height (Hormay 1943; Stanton 1959; Plummer and others 1968), stem layering (Nord 1965; Plummer and others 1957), ability to fix nitrogen (Klemmedson and Feruson 1969), and nutritive content (Giunta and others 1978). Wagle (1958) reported wide variation in growth of bitterbrush ecotypes in response to latitude, elevation, and soils. Stanton (1959) found differences in cold tolerance between central Oregon and northern California populations. With this great amount of variation within and between species, managers must carefully consider which characteristics are best suited for their specific needs before seeding within a specific habitat type. Seed sources have been shown to influence survival of seeded stands of bitterbrush (Plummer and others 1957).

Giunta and others (1978) summarized the following attributes that bitterbrush ecotypes possess in varying degrees: growth form, fire tolerance, rate of growth, period of growth, seed production, drought resistance, nutritional qualitites, heat tolerance, soil adaptation, cold hardiness, climatic adaptation, resistance to disease or insect damage, palatability to game or livestock, evergreen habit, vegetative reproduction, and shade tolerance.

STUDY AREAS AND METHODS

Since the late 1950's the project has evaluated 259 accessions of bitterbrush and cliffrose, with accessions originating from most areas throughout the Western United States. Of the 259 accessions, there were 141 accessions of antelope bitterbrush, 49 of cliffrose, 46 of antelope bitterbrush-cliffrose, and 1 of desert bitterbrush-antelope bitterbrush.

Species trials are currently located throughout Utah. However, special emphasis has been placed on the pinyon-juniper zone and adjacent associated community types. Table 1 lists the sites with their approximate elevation and the dominant vegetative type. These areas were selected to provide information on species vigor and their ease of establishment within the diverse pinyon-juniper sites and on the breadth of species and accession adaptation. Because most species trial sites were not protected from grazing animals, one cannot make fair or equitable comparisons between most characteristics of the different populations. The comparisons in this paper deal more specifically with longevity, vigor, and stand rating between populations of bitterbrush, cliffrose, and bitterbrush-cliffrose crosses.

When possible, performance ratings were made at least once each year the first 3 years after planting and thereafter at 3 to 5 year intervals. Performance ratings on plants grown on many sites began as early as 1956.

Plot size is variable, depending on how many species or accessions (populations) were to be planted on a site. Each selected accession was randomly planted at least twice on each site in shallow furrows 5 to 10 ft (1.52 to 3.05 m) long.

Species plot evaluations included some of the following characteristics: type of planting, location of site, date of planting, date of rating, species name, accession number (which included date and area from which the seed was collected), plot number, number of plants, plant density along the furrow, stand rating, average crown in inches, average weight in grams, rooted frequency along furrow, average percent utilization, state of development, growth habit, type of reproduction, seed production, and seedling vigor.

Table 1.--List of areas in a study of bitterbrush, cliffrose, and bitterbrush-cliffrose communities.

Area	Name	Location and county	Elevation in feet (meters)	Vegetation type
01	Dahl's Dugway	Ephraim Canyon, Sanpete	7,200 (2,195)	Mountainbrush
02	Rasmusson's	Ephraim Canyon, Sanpete	5,700 (1,737)	Pinyon-juniper: Sagebrush
03	Levan Dry Farm	Levan, Juab	5,200 (1,585)	Dry farm: sagebrush
04	Black Mountain	Salina Canyon, Sevier	6,000 (1,829)	Pinyon-juniper: sagebrush, cheatgrass brome
05	Pioneer Road	Fillmore, Millard	6,000 (1,829)	Pinyon-juniper: mountain brush
06	Fillmore Dump	Fillmore, Millard	5,400 (1,646)	Dry farm: sagebrush
07	Pinto	Pinto, Washington	6,000 (1,829)	Pinyon-juniper: mountainbrush
08	Ellickers	Summit, Iron	5,800 (1,768)	Homestead: sagebrush, pinyon-juniper
09	Brigham Burn	Brigham City, Box Elder	5,200 (1,585)	Sagebrush: cheatgrass brome
10	Major's Hillside	Ephraim Canyon, Sanpete	7,100 (2,164)	Pinyon-juniper: mountainbrush
11	Beaver Bench	Beaver, Beaver	6,300 (1,920)	Pinyon-juniper: sagebrush
12	Jackson Springs	Gunlock, Washington	4,000 (1,219)	Pinyon-juniper: blackbrush, desert shrub
13	Indian Peaks Dry Farm	Indian Peak Wildlife Management Area, Beaver	7,000 (2,134)	Pinyon-juniper: sagebrush
14	Indian Peaks cleared area	Same as preceding	7,000 (2,134)	Pinyon-juniper: sagebrush
15	Indian Peaks Burn	Same as preceding	7,000 (2,134)	Pinyon-juniper: sagebrush
16	Ephraim Roadcut	Ephraim Canyon, Sanpete	6,800 (2,073)	Mountainbrush
17	Kamas	Kamas, Summit	7,000 (2,134)	Mountainbrush
19	Lake Hill	Ephraim Canyon, Sanpete	8,000 (2,438)	Aspen: fir
20	Orem Burn	Orem, Utah	5,000 (1,524)	Mountainbrush: sagebrush, grass
22	North Holden	Holden, Millard	5,600 (1,707)	Pinyon-juniper: sagebrush
24	Cyclone Flat	W. Blanding, San Juan	6,600 (2,012)	Pinyon-juniper
25	Alkali Point	E. Blanding, San Juan	6,100 (1,859)	Pinyon-juniper
26	Peter's Point	N. Monticello, San Juan	7,200 (2,195)	Pinyon-juniper: sagebrush
27	Huntington	Huntington, Emery	5,800 (1,768)	Pinyon-juniper: sagebrush
28	Fairview Canyon	Fairview, Sanpete	6,400 (1,951)	Mountainbrush
29	Hobble Creek	Springville, Utah	4,800 (1,463)	Mountainbrush: sagebrush
30	Manti Dump	S. Manti, Sanpete	5,900 (1,798)	Pinyon-juniper: sagebrush (blacksage)
31	Majors Nursery	Ephraim Canyon, Sanpete	7,100 (3,164)	Mountain brush
32	Triangle Mt.	Salina Canyon, Sevier	6,500 (1,981)	Pinyon-juniper
33	Indian Peaks	Indian Peaks Wildlife Management Area, Beaver	7,000 (2,134)	Pinyon-juniper
34	Wallsburg	Wallsburg, Wasatch	5,800 (1,768)	Sagebrush: cheatgrass brome

Table 1.--(Continued)

35	East Manti	Manti, Sanpete	5,900 (1,798)	Sagebrush
36	Manti Sheep Trail	Manti, Sanpete	6,000 (1,829)	Pinyon-juniper: cheatgrass brome
37	Rabbit Gulch	E. Duchesne, Duchesne	6,300 (1,920)	Pinyon-juniper: sagebrush
39	John August Lake	John August Lake, Sanpete	10,300 (3,139)	Sub Alpine
41	Tobin Bench	Veyo, Washington	4,500 (1,372)	Blackbrush: pinyon-juniper, desert shrub
42	West Cedar City	Cedar City, Iron	5,700 (1,737)	Sagebrush: greesewood
43	Wingate Mesa	Fry Canyon, San Juan	6,900 (2,103)	Pinyon-juniper
44	Gunnison	Gunnison, Sanpete	5,200 (1,585)	Shadscale: saltdesert
45	Marysvale	Marysvale, Piute	6,000 (1,829)	Pinyon-juniper
46	Rulon Mortenson's	W. Ephraim, Sanpete	5,700 (1,737)	Greasewood: saltbush
47	Taylor Flat	Browns Park, Daggett	5,800 (1,768)	Pinyon-juniper: sagebrush
48	Santa Clara	Santa Clara, Washington	3,000 (914)	Desert shrub
49	Bald Mountain	Ephraim, Sanpete	5,700 (1,737)	Pinyon-juniper
50	Nephi Canyon	Nephi, Juab	5,600 (1,707)	Pinyon-juniper: mountainbrush
51	Big Buck	Dutch John, Daggett	6,600 (2,012)	Pinyon-juniper: sagebrush, bitterbrush
52	Omans	Gordon Creek, Carbon	7,200 (2,195)	Sagebrush, pinyon-juniper
53	College Farm	Ephraim, Sanpete	5,600 (1,707)	Sagebrush: grass
54	Millville	Millville, Cache	5,000 (1,524)	Mountainbrush, sagebrush
55	Mona	Mona, Juab	5,800 (1,768)	Sagebrush: grass
58	Henry Mountains Deer and cattle out	Henry Mountains, Garfield	7,600 (2,316)	Pinyon-juniper
59	Henry Mountain Cattle out-deer in	Henry Mountains, Garfield	7,600 (2,316)	Pinyon-juniper
60	Chevron Chemical[1]	Vernal, Uintah	6,600 (2,012)	Pinyon-juniper: black sagebrush grass
61	Springville	Springville, Utah	4,600 (1,402)	Sagebrush: grass
62	Pretty Valley	N. Manti, Sanpete	6,400 (1,951)	Pinyon-juniper: mountainbrush

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[1]Site numbers not listed are "out".

A computer program helped organize, analyze, and summarize the large amounts of data. A synthetic index value was determined by selecting the best performing accession on each site. This was done by comparing the average stand value for each accession and giving 8 points for the best performing accession and as low as 1 point for the poorest "best of eight" accessions. Average rank value was then calculated (maximum rank value would be 8.0). To determine which accessions exhibited the best overall rating on the most sites within the state, the average rank value was summed with the total number of sites on which it was one of the best eight performing accessions. This summed value is the index value. The best overall performing accessions showed the highest index value.

The selection of the best performing accessions, as determined by computer analysis, is shown in table 2. Accessions with the largest index values are considered the best. Only the "five" best performing accessions were used in the table. Other terms used in table 2 include vigor, longevity, stand, and rank.

Table 2.--The best performing accessions of bitterbrush, cliffrose, and bitterbrush-cliffrose crosses

Species	Accession number	Accession origination	Average Rank	Average Stand	Average Longevity	Average Vigor	Average Index
Cliffrose	U 9	Pioneer Rd. UT	7.5	6.8	15.2	6.8	24.5
	U 20	American Fork, UT	6.3	5.4	9.7	7.0	16.3
	U 16	Orem, UT	5.8	4.7	8.4	7.0	13.7
	U 22	Central, UT	7.0	6.2	8.1	5.5	13.0
	U 1	Oak Creek, UT	7.0	7.0	10.0	5.5	12.0
Desert bitterbrush	U 2	Moody Creek, UT	6.9	6.3	13.2	6.3	25.9
	U 5	George Creek, CA	7.1	5.9	12.2	NR*	21.1
	U 4	McMurray Meadows, CA	6.8	7.0	9.5	7.0	11.8
	U 8	Pioche, NV	6.7	6.8	10.2	3.0	9.6
	U 6	White Mountain Inyo Co, CA	8.0	4.5	20.0	6.0	9.0
Desert bitterbrush X antelope bitterbrush	U 1	Benton Station, CA.	7.8	6.2	7.0	6.9	11.8
Desert bitterbrush X cliffrose	U 5	Snow Canyon, UT	8.0	6.0	4.0	5.0	9.0
	U 3	Delmar Pass, NV	8.0	3.7	12.0	4.0	9.0
	U 4	Slaughter Creek Utah	8.0	2.0	3.0	6.0	9.0
Antelope bitterbrush	U 31	Fountain Green, UT	5.9	5.6	11.4	6.2	31.8
	U 3	Starvation Can., UT	5.6	5.1	8.4	NR	19.6
	U 28	Mt. Pleasant, UT	5.8	5.9	8.8	6.9	17.1
	U 14	Salt Lake Co., UT	7.1	6.2	7.4	6.0	12.5
	U 50	Spring City, UT	6.5	6.4	18.0	6.5	11.8
Antelope bitterbrush X cliffrose	U 10	S. Mt. Pleasant, UT	5.9	6.6	10.1	6.0	14.9
	U 16	Mt. Dell Res., UT	4.5	4.7	16.4	6.7	12.5
	U 11	Fountain Green, UT	7.2	7.3	25.2	4.5	12.2
	U 21	N. Mt. Pleasant, UT	6.5	3.6	10.9	4.0	10.5
	U 27	Enterprise, UT	6.3	4.6	6.5	6.2	10.3

*NR= No record, the project did not use vigor ratings until early 1970's.

Vigor is a subjective measurement or expression on a plant's appearance and how actively healthy and well balanced plant growth is. This is an average value for all sites it was grown on. The maximum value is 10. As subjective as this measurement is it has been found to be very reflective of plant performance and found to be quite consistent among those who rate the species plots.

Longevity is the number of years the accession has grown on a specific site since the initial planting. This again is an average value for all sites on which it has been grown.

Stand is a combined value of percent cover (value of 1-5) and plant distribution along the furrow (value of 1-5). Because it is the only measurement that has consistently been used in rating species performance since the beginning of the project it is the best measurement that can be used to help determine which rank value each accession has. The maximum value for stand is 10.

Rank is an average value of how well each accession performed when compared with the other accessions for a given species on a site-for-site basis. Maximum value attainable is 8. Some species within table 2 do not list the five best accessions, because either there were not five accessions collected for a specific species, or the minimum parameters selected on the computer program were too stringent. Accessions having values less than 3 for vigor and 3 years longevity were dropped.

Most of the accessions were collected by private seed collectors for reasons that were not necessarily connected to the selection of characteristics that this project would have looked for, but were characteristics the seed collectors chose. In most instances seeds were collected from stands producing large amounts of seed that were easy to collect. Most such stands were usually composed of plants 3 ft (.91 m)or more in height, with an upright growth habit. Large amounts of seed would indirectly indicate good vigor, while an upright growth form would make it more useful in most situations for revegetation of deer winter range.

An additional study was initiated in 1980 at a nearby protected "common garden" with over 50 selected accessions of bitterbrush, cliffrose, and bitterbrush-cliffrose crosses to help in better determining differences in morphological, phenological, and genetic characteristics.

RESULTS AND DISCUSSION

Accession U9 had the best cliffrose index value (table 2). Accessions U20, U16, U22, and U1 were grouped closely together near the U9 index value. All these accessions are similar morphologically except that some appear to grow on more sites than others as indicated by their respective index values.

Desert bitterbrush accessions U2 and U5 were by far the best performing populations (table 2). Both are high elevation ecotypes that come from the most northerly populations of desert bitterbrush in Utah and California. The next three accessions (U4, U8, and U6) have somewhat lower index values as a group.

Only one accession (U1) of desert bitterbrush crossed with antelope bitterbrush has been collected and grown. However, U1 has good values for stand and vigor (table 2). It is from within the area where the most northerly populations of desert bitterbrush occur in northeastern California.

Only seven accessions of the desert bitterbrush crossed with cliffrose were grown on species trial plots. Of these seven, only three showed very much promise, and of these only accession U5 from Snow Canyon had an acceptable stand rating (table 2).

Antelope bitterbrush accession U31 (table 2) was by far the best performing population (index value 31.8). Technically, it was in a class by itself. It is a large, upright, robust plant. On the native site, it is on the average 6 to 8 ft (1.83 m-2.44 m) high and with a crown of 6 or more ft (1.83 m). Seed was collected from the original source and planted on a site near the mouth of Hobble Creek Canyon to help develop a more dependable seed source for this accession. There, it has shown another good characteristic that is not evident on the native site. Whenever a stem or branch touches the ground it aggressively develops roots. The other accessions are grouped closely together with index values ranging from 19.6 to 11.8. All five of these accessions have very similar stand vigor ratings.

The antelope bitterbrush crossed with cliffrose accessions all have index values of almost the same magnitude (table 2). They were grouped so closely it is difficult to determine which is really "best" without first looking more closely at stand and vigor ratings. Overall, it would appear that U10 was the "best".

In summary, of all the 259 accessions grown on sites in Utah, only 24 exhibit good enough rank, stand, vigor, and index values to be of use when planted within the extensive pinyon-juniper type.

PUBLICATIONS CITED

Billings, W. D. The environmental complex in ralation to plant growth and distribution. Quarterly Review of Biology 27(3):251-265. 1952.

Blaisdell, James.; Walter F. Meuggler. Sprouting of bitterbrush (Purshia tridentata) following burning or top removal. Ecology 379(2):365-370. 1956.

Driscoll, Richard S. Sprouting bitterbrush in central Oregon. Ecology 44(4):820-821. 1963.

Giunta, Bruce C.: Richard Stevens; Kent R. Jorgensen: A. Perry Plummer. Antelope bitterbrush--an important wildland shrub. Utah State Division of Wildlife Resources, Publ. No. 78-12; 1978. 48 p.

Hormay, A. L. Bitterbrush in California. U.S. Department of Agriculture Forest Service research Note 34, California Forest and Range Experiment Station. 1943. 13 p.

Klemmedson, J.O.; R. B. Ferguson. Response of bitterbrush seedlings to nitrogen and moisture on granite soil. Soil Soc. Amer. Proc. 33(6):962-966. 1969.

Nord, Eamar C. Bitterbrush ecology--some recent findings. U.S. Department of Agriculture Forest Service Research Note 34; California Forest and Range Experiment Station. 1943. 13 p.

Nord, Eamar C. Autecology of bitterbrush in California. Ecological Monographs 35(3): 307-334. 1965.

Plummer, A.P.; D.R. Christensen; S.B. Monsen. Restoring big game range in Utah. Utah Division of Fish and Game Publ. 68-3; 1968. 183 p.

Plummer, A.P.; D.R. Christensen; Richard Stevens; Kent R. Jorgensen, Highlights, results, and accomplishments of game range restoration studies. Utah State Division of Fish and Game Publ. 70-3. 1970. 94 p.

Plummer, A.P.; R.L. Jensen; H.D. Stapley. Job completion report for game forage revegetation project. Utah State Department of Fish and Game Information Bulletin No. 31; 1957. 128 p.

Stanton, F.W. Autecological studies of bitterbrush (Purshia tridentata) Pursh (DC). Ph.D. Thesis. Oregon State University, Corvallis; 1959. 203 p.

Wagle, R.F. Early growth in bitterbrush and its relation to environment. Ph.D. Thesis. University of California, Berkeley; 1958. 271 p.

SURVIVAL AND GROWTH OF APACHE-PLUME, STANSBURY CLIFFROSE, AND SELECTED SOURCES OF ANTELOPE BITTERBRUSH IN NORTHEAST OREGON[1]

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ABSTRACT

Performance of transplants from single geographic sources of Apache-plume and cliffrose and eight sources of antelope bitterbrush were evaluated for 6 years in a uniform garden on shrub-steppe rangeland. Growth and survival of most shrubs was good. A bitterbrush source from a forest ecotype was preferred by insects and suffered 76 percent mortality after three seasons of defoliation.

INTRODUCTION

Antelope bitterbrush (Purshia tridentata [Pursh] DC.)[3] occurs in a wide array of environments throughout interior western North America. Adaptation to environmental features such as soils, climate, fire, and insects has resulted in ecotypes differing in morphology, growth form, palatability, fire tolerance, drought resistance, and other characteristics (Alderfer 1977; Guinta and others 1978; Monsen and Christensen 1975; Nord 1965). Knowledge of these attributes is needed for selecting plant materials for particular environments in range improvement projects as well as for genetic development of superior shrubs.

Plant materials for improving wildlife forage and cover are being evaluated in a uniform garden on the Keating mule deer winter range in Baker County, Oreg. The comparatively harsh environment of the garden is characteristic of many similar depleted shrub-steppe ranges that could benefit from range rehabilitation. Some promising species may be selected by land managers for operational projects. Most, however, will be evaluated further in outplantings representing a range of growing conditions.

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[3] Sources for scientific and common names of plants are Garrison and others (1976), Holmgren and Reveal (1966), and Plummer and others (1977).

This paper summarizes 6 years of Keating garden data on the survival and performance of transplants of eight geographic sources of antelope bitterbrush and single sources of Stansbury cliffrose (Cowania mexicana stansburiana [Torr.] Jeps.) and Apache-plume (Fallugia paradoxa [D. Don] Endl.).

STUDY AREA

The garden is on land administered by the Bureau of Land Management 30 miles (48 km) east of Baker, Oreg. It lies on gently rolling benchland above the Powder River canyon at an elevation of approximately 3,200 ft (980 m). Annual precipitation is 12 inches (300 mm), occurring mainly as winter snow. Intermittent spring and fall rains may also provide significant moisture, but the summers are droughty as is characteristic of the Pacific Northwest. Temperature extremes may reach -30° F (-35° C) in the winter and 100° F (38° C) during the summer; the frost-free growing season is estimated to be 145 days.

Soils are moderately deep and of granitic origin. They have been tentatively classified as fine, montmorillonitic, mesic, Calcic Argixerolls of the Brownscombe series.

Plant communities of the Keating range reflect past disturbance by fire, grazing, abandoned farming, and most recently, extensive grass seeding. The garden is in a portion of a standard crested wheatgrass (Agropyron desertorum Schult.) seeding that was fenced to exclude deer and livestock. Surrounding communities are characterized by basin big sagebrush (Artemisia tridentata tridentata Nutt.), rabbitbrush (Chrysothamnus spp. Nutt.), cheatgrass brome (Bromus tectorum L.), medusahead wildrye (Elymus caput-medusae L.), Sandberg's gluegrass (Poa sandbergii Vasey), numerous annual and biennial forbs, and scattered occurrences of bearded bluebunch wheatgrass (Agropyron spicatum [Pursh] Scribn. and Smith). Local ranchers and land managers suggest that antelope bitterbrush was once an important component of some communities. Scattered, heavily browsed bitterbrush shrubs now occur only in the steep, rocky canyon below the garden.

METHODS

Description of Shrub Sources

The sources of shrubs included in the garden are briefly described in table 1. Those of antelope bitterbrush represented an array of contrasting environments and ecotypes found in the Pacific Northwest.

The Janesville source is a vigorous, erect ecotype occurring on an area with sandy, granitic alluvial soils in northeastern California. It was included because plantings in Utah and Idaho have shown superior growth over other sources (Monsen and Christensen 1975).

Boise Basin, Garden Valley, and Fort Hall sources are from Idaho seed collections. The Boise Basin source is a decumbent, spreading ecotype on the granitic cobble of dredge piles north of Boise. The Garden Valley source is an erect ecotype on coarse, granitic soils also north of Boise. The Fort Hall source is a semierect form growing on alluvial materials in the Snake River drainage north of Pocatello, Idaho.

Table 1.--Descriptions of seed sources of antelope bitterbrush, Stansbury cliffrose, and Apache-plume evaluated in the Keating uniform garden, Oregon

Species source	Elevation	Precipitation	Frost-free period	Soils	Growth habit
	m	mm	Days		
Antelope bitterbrush:					
Janesville, CA	1,312	254	120	Granitic	Erect
Boise Basin, ID	1,220	762	75	Granitic	Decumbent
Fort Hall, ID	1,220	432	120	Alluvial	Semi-erect
Garden Valley, ID	1,098	508	90	Granitic	Erect
Hat Rock, OR	107	203	170	Lacustrine	Erect
Keating, OR	793	305	145	Granitic	Erect
Pringle Falls, OR	1,312	508	<20	Pumiceous	Decumbent
Warner Mtn., OR	1,830	508	<100	Basaltic	Decumbent
Cliffrose:					
American Fork, UT	1,281	381	120	Sedimentary	Erect
Apache-plume:					
Richfield, UT	1,616	330	100	Sedimentary	Erect

The Oregon sources have the greatest environmental contrasts in the group. The Hat Rock source is a vigorous, erect ecotype growing on sandy soils deposited over basalt adjacent to the Columbia River near Hermiston. This source is the lowest in elevation and has the hottest, driest, and longest growing season. The local Keating source was collected from shrubs in the rocky bluffs along the Powder River below the garden. It also represents an ecotype that developed in a harsh, dry environment with warm growing seasons. In contrast, the Pringle Falls source represents the other climatic extreme for antelope bitterbrush. This fine-leafed, decumbent ecotype occurs in dense stands exceeding 8,000 shrubs per acre (19,760/ha) (Edgerton, this symposium) that dominate the understory of extensive lodgepole pine (Pinus contorta Dougl. ex Loud.) communities in the pumice region of central Oregon. Light and temperature appear to limit growth more than moisture availability; frosts are common during the growing season. The Warner Mountains source of south-central Oregon and the Pringle Falls source are similar in morphology. However, the Warner Mountains shrubs developed on basalt-derived soils without a tree overstory and represent the highest elevation ecotype studied in the garden.

Neither Stansbury cliffrose nor Apache-plume are native to the Pacific Northwest. Both, however, have grown well in southern Idaho plantations. There is value in determining the amplitude of adaptability of these promising shrubs outside their native ranges. Their inclusion in plantings on depleted ranges could potentially increase the diversity of forage and cover available to wintering wildlife. Single Utah sources of each species were included in the uniform garden.

Planting

In April 1976 at three Keating garden locations, 10 shrubs of each source were transplanted in rows in a 6-ft (1.8-m) spacing (total of 30 shrubs of each source). Six of the bitterbrush sources and the cliffrose and Apache-plume shrubs were -month-old container seedlings grown in a greenhouse. Fort Hall and Garden Valley bitterbrush sources were 1/0 bareroot nursery stock. The estimated average seedling height at planting was 3 inches (8 cm).

Competing vegetation was removed by a disc plow prior to planting. Hand planting was accomplished using both planting bars and spades.

Garden Maintenance

Competing vegetation adjacent to the shrubs was removed twice each growing season by mechanical cultivation, primarily to provide uniform growing conditions for performance comparisons. The shrubs received neither fertilizer nor supplemental water.

The fence surrounding the garden protected the shrubs from deer and livestock browsing. Mice, rabbits, and gophers foraged on a few shrubs. Grasshoppers were present each growing season, with unusually high populations in 1977, 1978, and 1979. No insect control measures were used either within the garden or on the surrounding rangeland.

Measurements

Survival and performance of each transplanted shrub was assessed each year at the close of the growing season in September. We counted surviving plants and measured maximum height and crown spread. Total aboveground biomass was determined using a modification of the weight estimate technique of Pechanec and Pickford (1937); prior to data collection, technicians trained themselves to accurately estimate the individual shrub weights by clipping and weighing different sizes of branches.

Measurements were recorded in metric units and are so presented in this paper. We estimated relative vigor, flower and fruit production, and insect occurrence and damage.

RESULTS

Tables 2, 3, and 4 summarize growth of shrubs during the first six growing seasons as reflected by measurements of average maximum height, average maximum crownspread, and average aboveground biomass.

Table 2.--Height of antelope bitterbrush, Stansbury cliffrose, and Apache-plume shrubs in the Keating uniform garden, Oregon

	Mean maximum height ± 95 percent confidence interval					
Species and source	1976	1977	1978	1979	1980	1981
			cm			
Antelope bitterbrush:						
Janesville, CA	26 ± 2	44 ± 2	72 ± 3	76 ± 3	80 ± 3	88 ± 4
Boise Basin, ID	24 ± 2	41 ± 3	65 ± 3	69 ± 3	72 ± 3	76 ± 3
Fort Hall, ID	20 ± 7	31 ± 6	51 ± 6	50 ± 7	55 ± 5	61 ± 3
Garden Valley, ID	21 ± 3	38 ± 3	64 ± 4	67 ± 4	72 ± 4	78 ± 5
Hat Rock, OR	24 ± 3	40 ± 4	69 ± 5	71 ± 5	74 ± 5	83 ± 6
Keating, OR	25 ± 2	42 ± 4	67 ± 3	69 ± 3	72 ± 3	78 ± 3
Pringle Falls, OR	19 ± 3	34 ± 3	58 ± 4	52 ± 4	43 ± 14	47 ± 12
Warner Mtn., OR	22 ± 3	36 ± 4	64 ± 4	65 ± 4	62 ± 4	68 ± 5
All bitterbrush	23	38	64	65	66	72
Cliffrose:						
American Fork, UT	22 ± 2	34 ± 3	61 ± 3	64 ± 3	65 ± 4	80 ± 5
Apache-plume:						
Richfield, UT	47 ± 4	58 ± 4	80 ± 6	77 ± 4	88 ± 6	103 ± 6

Table 3.--Crown spread of antelope bitterbrush, Stansbury cliffrose, and Apache-plume shrubs in the Keating uniform garden, Oregon

Species and source	Mean maximum crown spread ± 95 percent confidence interval 1976	1977	1978	1979	1980	1981
	- - - - - - - - -	- - - - -	- - - - - cm	- - - - -	- - - - -	- - - - -
Antelope bitterbrush:						
Janesville, CA	17 ± 2	45 ± 4	88 ± 6	107 ± 6	114 ± 6	127 ± 7
Boise Basin, ID	21 ± 2	57 ± 3	108 ± 4	131 ± 4	130 ± 4	138 ± 5
Fort Hall, ID	24 ± 11	58 ± 11	100 ± 6	119 ± 9	118 ± 9	124 ± 10
Garden Valley, ID	17 ± 3	49 ± 6	95 ± 10	113 ± 9	124 ± 9	133 ± 10
Hat Rock, OR	22 ± 5	61 ± 6	108 ± 7	128 ± 7	129 ± 8	144 ± 9
Keating, OR	25 ± 4	61 ± 6	111 ± 9	130 ± 7	132 ± 6	137 ± 8
Pringle Falls, OR	40 ± 6	70 ± 6	104 ± 7	106 ± 7	93 ± 29	106 ± 22
Warner Mtn., OR	27 ± 5	59 ± 6	98 ± 6	113 ± 7	110 ± 7	121 ± 10
All bitterbrush	24	58	102	118	119	129
Cliffrose:						
American Fork, UT	16 ± 3	37 ± 4	66 ± 4	78 ± 6	80 ± 5	91 ± 7
Apache-plume:						
Richfield, UT	38 ± 4	56 ± 4	94 ± 8	98 ± 6	113 ± 11	141 ± 11

Table 4.--Aboveground biomass of antelope bitterbrush, Stansbury cliffrose, and Apache-plume shrubs in the Keating uniform garden, Oregon

Species and source	Mean dry weight ± 95 percent confidence interval 1976	1977	1978	1979	1980	1981
	- - - - - - - - -	- - - - -	- - - - - Grams	- - - - -	- - - - -	- - - - -
Antelope bitterbrush:						
Janesville, CA	5 ± 1	6 ± 10	683 ± 89	[1]	824 ± 65	[2]
Boise Basin, ID	5 ± 1	73 ± 23	658 ± 83		851 ± 49	
Fort Hall, ID	6 ± 5	39 ± 22	326 ± 97		490 ± 80	
Garden Valley, ID	7 ± 3	69 ± 17	563 ± 104		847 ± 113	
Hat Rock, OR	8 ± 3	78 ± 16	704 ± 143		799 ± 95	
Keating, OR	11 ± 6	83 ± 18	805 ± 138		867 ± 81	
Pringle Falls, OR	13 ± 6	81 ± 21	522 ± 115		164 ± 128	
Warner Mtn., OR	6 ± 3	69 ± 35	71 ± 130		653 ± 126	
All bitterbrush	8	70	604		687	
Cliffrose:						
American Fork, UT	3 ± 1	33 ± 7	394 ± 78		452 ± 43	
Apache-plume:						
Richfield, UT	12 ± 2	51 ± 7	262 ± 31		497 ± 121	

[1] No data were taken because of grasshopper defoliation.

[2] No data were taken.

First Year

Moisture conditions during the spring and early summer of 1976 apparently favored the establishment and growth of shrubs. All of the container bitterbrush transplants survived the first season. Fort Hall and Garden Valley sources experienced 20 and 5 percent mortality, respectively, probably due to preplanting condition of the bareroot transplants.

Height and crown spread of shrubs tended to reflect characteristics of the parent stands. Janesville bitterbrush grew rapidly in height with a relatively narrow crown. However, crowns of the decumbent Pringle Falls bitterbrush source were twice as wide as high.

All of the Stansbury cliffrose and Apache-plume transplants survived. Growth of Apache-plume was exceptional, averaging over 40 cm in height (fig. 1).

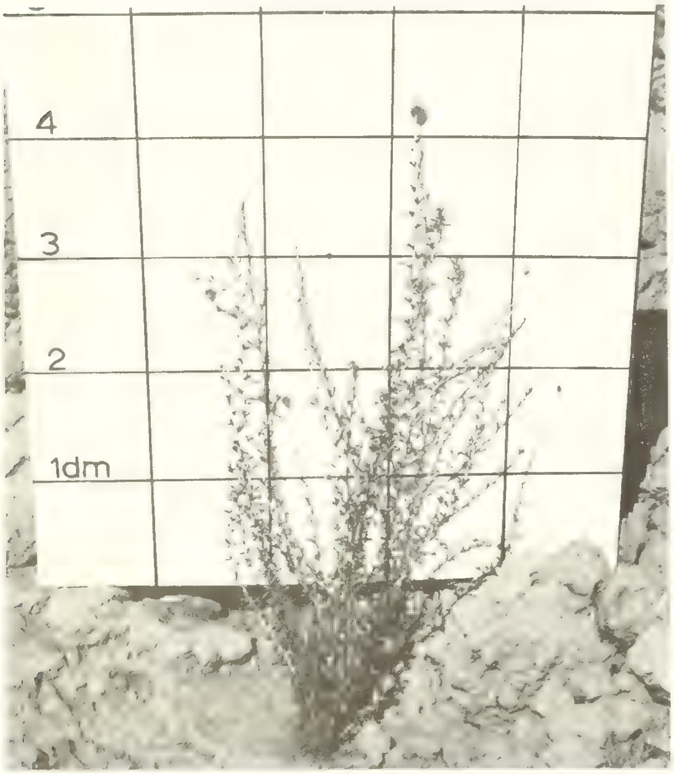

Figure 1.--Apache-plume transplant after one growing season (1976) in the Keatig uniform garden, Oregon.

Second Year

Eastern Oregon experienced near-record drought during the 1976-77 winter and the 1977 growing season. Despite unfavorable growing conditions, mortality was negligible and all shrubs produced vigorous twig growth. Average height nearly doubled and increases in crown spread were even greater. Overall average aboveground biomass of the eight bitterbrush sources increased from 8 g to 67 g.

In early July 1977, an increasing abundance of grasshoppers was observed in the garden and on the surrounding rangeland. By mid-July evidence of extensive feeding was noted, first on oldman wormwood (Artemisia abrotanum L.), then on other shrubs including honeysuckle (Lonicera spp. L.), cherry (Prunus spp. L.), currant (Ribes spp. L.), antelope bitterbrush, cliffrose, and Apache-plume. On August 1 flushing counts on 25 circular plots (1-m diameter each) systematically located across the garden indicated an average density of seven grasshoppers per square meter. Genera and species identified from a partial collection included Aulocara elliotti (Thomas)

Arphia pseudonietana (Thomas), Melanoplus sanguinipes (F.), and Melanoplus foedus foedus Scudder or M. f. fluviatilis Bruner.[4] Estimates were not made of the number of each kind of grasshopper nor the extent of feeding by each.

Table 5 shows estimates of damage to leaves and bark. Apparently the Pringle Falls bitterbrush source was preferred over the other sources. Each of the shrubs of that source was nearly completely defoliated while feeding on other sources was largely confined to new growth near the tips of twigs (fig. 2). Occasional feeding was noted on the bark of small twigs of all shrubs.

Table 5.--Grasshopper damage to leaves and bark[1] and resulting mortality of antelope bitterbrush, Stansbury cliffrose, and Apache-plume shrubs in the Keating uniform garden, Oregon

Species and Source	Mean leaf area removed			Mean bark area removed			Mortality
	1977	1978	1979	1977	1978	1979	1977-81
	Percent						
Antelope bitterbrush:							
Janesville, CA	4	4	95	2	1	12	0
Boise Basin, ID	2	3	84	1	1	3	0
Fort Hall, ID	18	10	99	2	2	9	0
Garden Valley, ID	14	5	98	2	1	12	0
Hat Rock, OR	6	5	93	2	2	11	0
Keating, OR	7	6	100	1	2	14	0
Pringle Falls, OR	93	68	100	3	4	21	76
Warner Mtn., OR	20	20	100	2	2	14	7
Cliffrose:							
American Fork, UT	4	1	92	2	1	21	3
Apache-plume:							
Richfield, UT	23	22	66	8	5	24	7

[1] Includes bark of twigs and large stems.

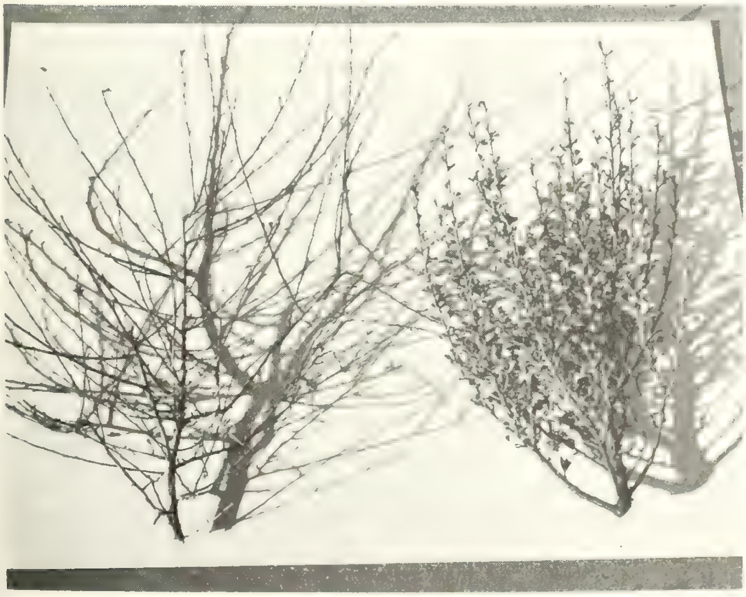

Figure 2.--Selective defoliation of antelope bitterbrush sources by grasshoppers; Pringle Falls, Oreg., source at left, Janesville, Calif., source at right.

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[4] Identification by G. B. Hewitt, Research Entomologist, USDA, SEA, Rangeland Insect Laboratory, Bozeman, MT 59717.

Third Year

Survival remained high during 1978. All shrubs continued vigorous growth. Apache-plume and the Janesville bitterbrush source were tallest, as expected. Crown spread of several bitterbrush sources exceeded 1 m.

Grasshoppers during mid- and late summer reached a density of $5/m^2$ in early August. Again they fed most heavily on the Pringle Falls bitterbrush source, but defoliation was less severe than in 1977.

Fourth Year

During the 1979 growing season grasshoppers were responsible for considerable damage to range forage and agricultural crops throughout much of eastern Oregon. Grasshopper density in the Keating garden exceeded $15/m^2$. During early and mid-July they again fed on the Pringle Falls source, but as preferred forage became less available and insect maturity progressed, feeding shifted to all of the bitterbrush sources. Leaves, succulent new twig growth, and twigs and bark were devoured (table 5).

Fall survival remained high. Accurate growth measurements were difficult because of the material removed by grasshoppers. Accordingly, both height and crown spread of most shrubs showed little, if any, growth. The Pringle Falls bitterbrush source, which received 3 years of heavy defoliation, decreased 6 cm in average maximum height from 1978 to 1979.

Fifth and Sixth Years

Grasshopper populations were much lower during the 1980 and 1981 growing seasons, allowing recovery of most shrubs. Although most shrubs had many dead twigs, only the Pringle Falls bitterbrush source suffered extensive mortality as the result of previous defoliation; only 7 of 30 shrubs (23 percent) survived. Survival of other shrubs exceeded 90 percent (table 5).

Growth during 1980, the fifth season, showed the apparent effects of defoliation the previous year. All bitterbrush sources showed an average height increase of only 1 cm. Several sources decreased in height. Crown spread and biomass were similarly affected.

During 1981, growth of most shrubs overcame the lull of 1980. All bitterbrush sources, Stansbury cliffrose, and Apache-plume showed modest increases in height and crown spread during 1981. All of the bitterbrush sources and Apache-plume also produced both flowers and seeds.

DISCUSSION AND CONCLUSIONS

The Keating garden is a valuable field laboratory for evaluating plant materials for range rehabilitation. Surprisingly, introduced shrubs such as cliffrose and Apache-plume plus most native bitterbrush from an array of sources were established and performed well in the relatively harsh environment that included drought and repeated insect attacks (fig. 3). Total height growth of bitterbrush and cliffrose compares well with that reported for a cultivated Utah planting (Monsen and Christensen 1975).

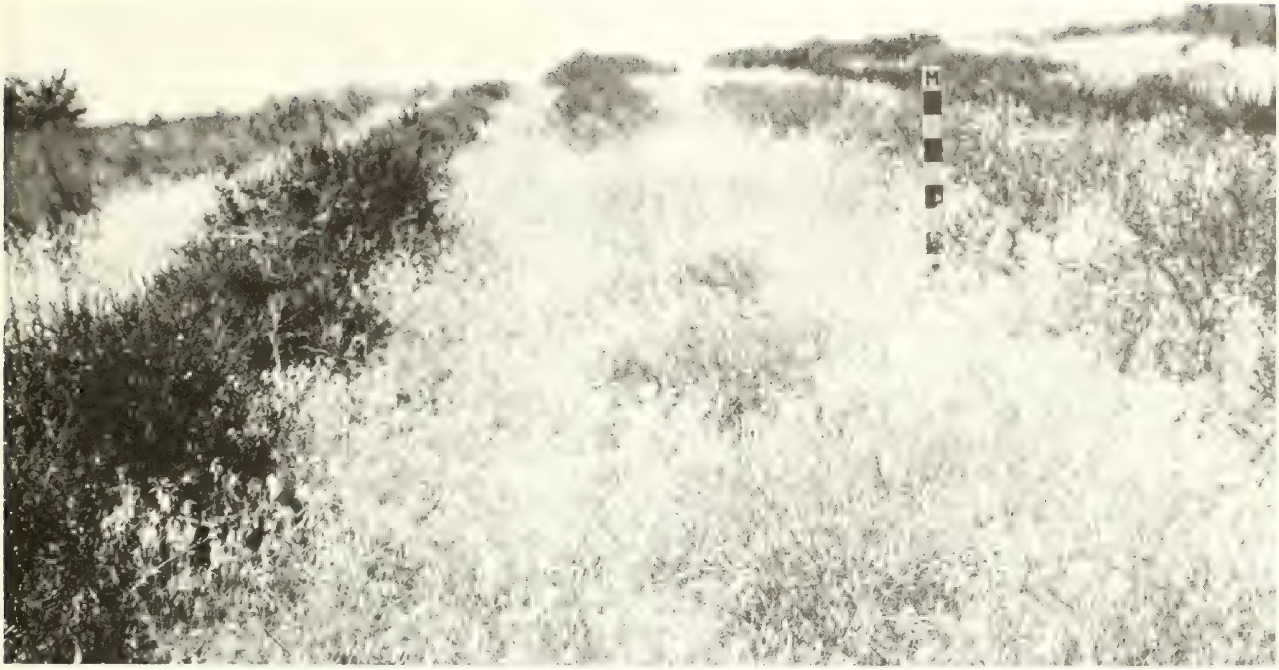

Figure 3.--Antelope bitterbrush sources in the Keating uniform garden after six growing seasons (1981). The Janesville, Calif., source is at left, foreground. The seemingly vacant center row illustrates mortality of the Pringle Falls, Oreg., source due to consecutive seasons of selective defoliation by grasshoppers.

Apparently those bitterbrush sources deserving further testing in outplantings include Janesville, Boise Basin, Garden Valley, Keating, and Hat Rock. Apache-plume and cliffrose showed promise in this study and should also be further evaluated. The Keating source ranked high in all performance measurements. It was clearly superior in production of biomass in 1978, a positive indication of its capability for rapid establishment. This should be considered an advantage in harsh rangeland environments where conditions favoring establishment are often of short duration. Because of its adaptability to the local environment, the Keating source remains the most reliable choice for use in revegetation projects in similar habitats.

As expected, shrubs in the garden developed growth forms and other characteristics such as leaf shape and color that tended to reflect their parent seed sources. The tall, upright form of progeny from, for instance, the Janesville source may be of particular value for ranges where improvement of cover or shelter for wintering animals is an important concern. Decumbent, layering forms are likely to have value in soil stabilization.

To our knowledge, selective feeding by grasshoppers on particular shrub ecotypes is previously unreported in the rangeland and related literature. Most studies report that herbaceous plants are the major components of the diet. Preferences vary widely according to the grasshopper species, their nutritional needs at different stages of maturity, and the availability and maturity of forage species (Hewitt 1977). It is not unusual, however, for the diet to include shrubs. Allred (1941) reported extensive damage to big sagebrush stands in Wyoming and Montana. Holmgren and Basile (1959) noted that grasshoppers were a common problem in bitterbrush plantings, feeding on both seedlings and established shrubs. They found, as did our study, that defoliation in consecutive years can result in mortality.

In our study, grasshoppers repeatedly defoliated the Pringle Falls source. This ecotype developed in a cool forest environment where significant insect buildups are infrequent, and apparently it lacks the resistance present in rangeland ecotypes less vulnerable to insect attack. Such results suggest that more information on insect forage preferences could have far-reaching implications in selection of plant materials for range revegetation. They also underscore the importance of evaluating potential plant materials in uniform gardens and outplantings over a period long enough to afford a range of environmental conditions.

Plantings such as the Keating garden are of value in assessing the range of adaptability and relative productivity of promising species and ecotypes. They also increase our knowledge of more subtle characteristics, such as insect preferences, which might not be detected in native stands.

PUBLICATIONS CITED

Alderfer, J. M. A taxonomic study of bitterbrush (Purshia tridentata (Pursh) DC.) in Oregon. Corvallis, OR: Oregon State University; 1977. 197 p. M.S. thesis.

Allred, B. W. Grasshoppers and their effect on sagebrush on the Little Powder River in Wyoming and Montana. Ecology 22: 387-392; 1941.

Garrison, G. A.; Skovlin, J. M.; Poulton, C. E.; Winward, A. H. Northwest plant names and symbols for ecosystem inventory and analysis. 4th ed. Gen. Tech. Rep. PNW-46. Washington, DC: U.S. Department of Agriculture, Forest Service; 1976. 263 p.

Guinta, Bruce C.; Stevens, R.; Jorgensen, K. R.; Plummer, A. P. Antelope bitterbrush--an important wildland shrub. Resources Publ. No. 78-12. Salt Lake City, UT: Utah State Division of Wildlife; 1978. 48 p.

Hewitt, G. B. Review of forage losses caused by rangeland grasshoppers. Misc. Publ. No. 1348. Washington, DC: U.S. Department of Agriculture; 1977. 24 p.

Holmgren, R. C.; Basile, J. V. Improving southern Idaho deer winter ranges by artificial revegetation. Wildlife Bull. No. 3. Boise, ID: State of Idaho Department of Fish and Game; 1959. 61 p.

Holmgren, A. H.; Reveal, J. L. Checklist of the vascular plants of the Intermountain Region. Res. Pap. INT-32. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1966. 160 p.

Monsen, S. B ; Christensen, D. R. Woody plants for rehabilitating rangelands in the intermountain region. In: McKell, Cyrus M.; Blaisdell, James P.; Goodin, Joe R., eds. Wildland shrubs--their biology and utilization: international symposium; Logan, UT: Utah State University; July 1971. Gen. Tech. Rep. INT-1. Washington, DC: U.S. Department of Agriculture, Forest Service; Intermountain Forest and Range Experiment Station; 1975: 72-119.

Nord, E C. Autecology of bitterbrush in California. Ecol. Monogr. 35: 307-334; 1965.

Pechanec, J. F.; Pickford, G. D. A weight estimate method for the determination of range or pasture production. J. Amer. Soc. Agron. 29: 894-904; 1937.

Plummer, A. P.; Monsen, S. B.; Stevens, R. Intermountain range plant names and symbols. Gen. Tech. Rep. INT-38. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1977. 82 p.

PHENOLOGY AND GROWTH HABITS OF NINE ANTELOPE BITTERBRUSH, DESERT BITTERBRUSH, STANSBURY CLIFFROSE, AND APACHE-PLUME ACCESSIONS[1]

Nancy L. Shaw and Stephen B. Monsen[2]

ABSTRACT

Growth habits, growth rates, phenology, and seed production of antelope bitterbrush, desert bitterbrush, Stansbury cliffrose, and Apache-plume accessions grown on a common garden are described. The information aids in the selection of appropriate management practices and improved seed production efforts, and provides a basis for selecting accessions for breeding programs or revegetation projects.

INTRODUCTION

Extensive variation within many native Intermountain shrub species has evolved in response to the interaction of rich gene pools and diverse habitats (Stutz 1974; Giunta and others 1978). Accessions of important species have been selected from the array of available ecotypes for inclusion in range revegetation programs. Antelope bitterbrush (Purshia tridentata [Pursh] DC.) was used in early wildlife habitat restoration projects (Hormay 1943; Holmgren 1954; Plummer and others 1955). Specific accessions of this species have also improved esthetics and reduced erosion on disturbed sites (Tiedemann and others 1976; Monsen and Plummer 1978; Everett 1980).

The related species -- cliffrose (Cowania mexicana D. Don var. stansburiana [Torr.] Jeps.), Apache-plume (Fallugia paradoxa [D. Don] Endl.), and desert bitterbrush (Purshia glandulosa Curran.) -- have also proven of value in revegetation projects (Blauer and others 1975; Plummer and others 1968). These species are drought tolerant and are prime candidates for ornamental use on nonirrigated sites. Palatable forms provide important winter forage for deer, cattle, and sheep. Desert bitterbrush and Apache-plume are somewhat fire tolerant, frequently resprouting following burning. Apache-plume is an excellent erosion control plant for disturbed sites in dry areas as it spreads vegetatively. All three species have potential for breeding programs as all hybridize with antelope bitterbrush (Stutz and Thomas 1964; Stutz 1974; Blauer and others 1975).

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Trials in Utah, Nevada, and Idaho during the past 30 years have identified important accessions of these species and their range of adaptation, growth characteristics and value in plantings (Plummer and others 1968; Blauer and others 1975; Giunta and others 1978). But additional knowledge of each species' floral phenology is required if adequate supplies of commercial seed are to be produced on a regular basis (Van Epps 1974; McArthur and others 1978). Studies of the floral sequence and seed development of each accession would provide data required for breeding programs, management of wildland stands to maximize seed production or permit stand regeneration, prediction of seed collection dates, and development of technology required to augment seed production under agricultural conditions (West and Wein 1971; Hopp and Blair 1973; Blauer and others 1975; Giunta and others 1978; Everett and others 1980). Comparisons of even-aged accessions of individual species planted in a common garden would aid in the identification of genetic variation in growth habits, timing of phenological stages, seed production capabilities, and susceptibility of seeds to damage by biotic and abiotic factors.

In the present study, we examined the growth habits and floral phenology of five accessions of antelope bitterbrush, two accessions of desert bitterbrush, and one accession each of Stansbury cliffrose and Apache-plume that were planted in a common garden near Boise, Idaho (table 1). Native stands of several of these accessions have been the subject of ecological studies (Ferguson and others 1963; Nord 1965; Alderfer 1977; Menke and Trlica 1981). Each accession has been tested extensively in selection trials and seeding projects in the Intermountain region (Plummer 1968; Monsen 1975; Giunta and others 1978; Monsen and Plummer 1978; Davis, unpubl. data, Monsen, unpubl. data, Stevens, unpubl. data). Commercial seed dealers regularly collect large quantities of Stansbury cliffrose seed from the Utah County, Utah, site and antelope bitterbrush seed from the sites at Lassen County, Calif.; Moffat County, Colo.; and Ada County, Idaho.

SITE DESCRIPTION

The study was conducted at the Boise Shrub Garden approximately 17 miles (27 km) northeast of Boise, Idaho. The 40 acre (16-ha) deer-proof exclosure was constructed on an east-facing terrace of granitic colluvium. Slopes range from 8 to 15 percent. Soils are dark greyish-brown or yellowish-brown gravelly, sandy loams.

Undisturbed areas within the exclosure are dominated by stands of mountain big sagebrush (*Artemisia tridentata* Nutt. var. *vaseyana* [Rydb.] B. Boi.) and threetip sagebrush (*Artemisia tripartita* Rydb.). Scattered antelope bitterbrush shrubs occur throughout the site. Understory grasses include Idaho fescue (*Festuca idahoensis* Elmer), squirreltail (*Sitanion hystrix* Nutt.), and Sandberg's bluegrass (*Poa sandbergii* Vasey). Spurred lupine (*Lupinus laxiflorus* Dougl. var. *calcaratus* [Kell.] Smith), hermit milkvetch (*Astragalus eremiticus* Sheld.), and storksbill (*Erodium cicutarium* [L.] L'Her.) are common forbs.

Climate of the site is semiarid with an 11-year (1970-81) average annual precipitation of 17 inches (43 cm). Approximately 80 percent of the annual precipitation falls from October through April. Most summer precipitation occurs as infrequent, high intensity thundershowers. Total precipitation in 1979 (the first year of study) was 24 percent below average while 1980 precipitation was near normal. Seasonal distribution of the precipitation was erratic during both years. For 1970 through 1981, the frost-free season averaged 126 days, with average dates of last spring and first fall frosts May 26 and October 1.

Table 1.--Cliffrose, Apache-plume, desert bitterbrush, and antelope bitterbrush accessions grown at the Boise, Idaho, Shrub Garden.

Species	Seed source	Elevation Ft	Annual precipitation Inches
Cowania mexicana stansburiana	Utah Co., Utah (American Fork)	5,100	15.0
Fallugia paradoxa	Sevier Co., Utah (Richfield)	5,300	8.3
Purshia glandulosa	Mono Co., Calif. (Benton Hot Springs)	5,700	5.9
Purshia glandulosa	Washington Co., Utah (Snow Canyon)	3,800	7.1
Purshia tridentata	Lassen Co., Calif. (Janesville)	4,300	16.9
Purshia tridentata	Moffat Co., Colo. (Maybelle)	6,300	11.0
Purshia tridentata	Ada Co., Idaho (Lucky Peak Res.)	3,200	16.9
Purshia tridentata	Carbon Co., Utah (Starvation Canyon)	7,000	23.2
Purshia tridentata	Juab Co., Utah (Eureka)	6,400	15.4

METHODS AND MATERIALS

Planting

The seven bitterbrush accessions were planted in 1973, and the cliffrose and Apache-plume accessions were planted in 1974. Native shrubs were cleared from the area prior to planting. Containerized seedlings of the antelope and desert bitterbrush accessions and 1-0 bareroot stock of the cliffrose and Apache-plume accessions were planted at 8-ft (2.4-m) spacings in two replications of 25 plants each. To reduce competition, each seedling was hand planted in the center of a 9-ft^2 (0.8 m^2) "scalp" from which approximately 2 inches (5 cm) of surface debris and soil, including weed seeds and roots, had been removed (Holmgren 1956). The site is mowed annually to control weeds and reduce the danger of wildfire. Rodent populations are controlled by baiting.

Data Collection

Five plants in each of the two replicated plots per species were selected at random for observations of leaf development, leader growth, and floral phenology. These observations were recorded for all nine accessions in 1979 and 1980. Survival, height, crown spread, vigor, and uniformity of the shrubs have been recorded annually since 1975. Incomplete data are available for the desert bitterbrush plots.

Leader growth and leaf development observations were followed annually with tagging of 10 leaf fascicles and four terminal leaders on each marked shrub. Development of the first new leaf in each marked fascicle was recorded from the earliest date of observable growth until the leaf reached its mature size and was fully expanded. Length of each marked terminal leader was recorded periodically throughout the growing season.

Floral phenology was followed annually with tagging of 10 flower buds on each of the marked shrubs. Each bud was examined separately on each observation date and assigned a rating value based on its stage of development. The type and extent of any observed damage to each flower or fruit were also recorded.

Timing of observations was dependent upon the rate of phenological development. Leaf development and floral stages were recorded weekly. Flowering and seed development stages were observed biweekly for 2 to 3 weeks following anthesis. Leader growth was measured semimonthly in May, June, and early July during the period of rapid growth and monthly from July through September during decreased growth. Yearly plant measurements and ratings were recorded in August.

Meteorological data have been collected since 1971 at the USDA Forest Service, Lucky Peak Nursery approximately 0.5 miles (8 km) north of the Shrub Garden. Precipitation, maximum and minimum temperatures, wind speed, and wind direction are recorded.

RESULTS

Vegetative Development

Growth rates and growth habits of the nine accessions studied are reported in table 2. Of the Apache-plume shrubs, 60 percent survived through the 1981 growing season while survival of each of the remaining accessions exceeded 90 percent. Attrition of the Apache-plume accession appears to be related to a lack of cold hardiness. One or two plants have succumbed each winter and six shrubs were lost during the winter of 1976-77. Varying degrees of dieback and recovery of additional Apache-plume plants have been observed each year.

All accessions retained their native growth habits and morphological characteristics when grown in the common garden. Nord (1965), Plummer and others (1968), and Giunta and others (1978) also found these traits to be maintained for antelope bitterbrush accessions grown on a number of experimental plots. The growth habits of individual accessions became apparent during the first growing season following planting as a result of differential height and crown growth, variation in branch flexibility, and the development of additional basal stems. The Carbon County and Juab County, Utah, and Moffat County, Colo., antelope bitterbrush accessions are very similar in growth habits. Numerous basal branches grow in a diffuse pattern and new leaders are initiated over the entire crown of the shrub. The Lassen County, Calif., antelope bitterbrush exhibits an erect growth habit with the crown developing from a small number of basal stems and new leader development concentrated in the upper portion of the plant. The growth habit of the Ada County, Idaho, antelope bitterbrush is intermediate between the other two forms. The Apache-plume and Washington County, Utah, desert bitterbrush accessions exhibited the greatest variation in growth habit, ranging from erect to diffuse.

Table 2.--Performance of antelope and desert bitterbrush, Stansbury cliffrose, and Apache-plum accessions at the Boise Shrub Garden

Accession	Survival (%)[1/] (July 1981)	Growth habit	Layering (% in 1981)	Vigor[2/] (mean 1975-1981, PUGL mean 1979-1981)	Uniformity[3/] (mean 1975-1981, PUGL mean 1979-1981)
COMES[4/] Utah Co., Utah	94	Erect	0	8	8
FAPA Sevier Co., Utah	60	Erect-Diffuse	0	6	7
PUGL Mono Co., Calif.	96	Diffuse	0	8	6
PUGL Washington Co., Utah	92	Erect-Diffuse	0	8	7
PUTR Lassen Co., Calif.	96	Erect	0	8	8
PUTR Moffat Co., Colo.	100	Diffuse	8	7	8
PUTR Ada Co., Idaho	100	Erect-Diffuse	2	8	8
PUTR Carbon Co., Utah	100	Diffuse	36	8	8
PUTR Juab Co., Utah	98	Diffuse	0	8	8

[1/] COMES and FAPA planted in 1973, PUGL and PUTR planted in 1974.
[2/] 0 = dead ... 9 = high vigor
[3/] 1 = growth form highly variable within the plot ... 9 = growth form uniform throughout the plot.
[4/] COMES - Stansbury cliffrose; PUGL - desert bitterbrush; FAPA - Apache-plume; PUTR - antelope bitterbrush

Table 3.--Mean annual height and crown measurements in inches of antelope and desert bitterbrush, Stansbury cliffrose, and Apache-plume accessions at the Boise Shrub Garden

Accession		1975	1976	1977	1978	1979	1980	1981
		Inches						
COMES[1]	Height	15.7	26.0	39.4	41.7	39.8	45.3	63.0
Utah Co., Utah	Crown	18.5	23.6	28.0	35.8	51.6	60.2	63.8
FAPA	Height	15.7	21.7	33.1	30.7	73.6	32.3	38.2
Sevier Co., Utah	Crown	15.0	27.2	27.2	28.7	33.9	42.5	42.1
PUTR	Height	23.6	29.5	37.0	45.7	45.7	48.0	57.5
Lassen Co., Calif.	Crown	25.2	27.6	38.6	45.3	61.8	68.9	64.2
PUTR	Height	24.4	26.0	30.7	28.3	35.0	32.7	37.0
Moffat Co., Colo.	Crown	39.8	53.1	59.1	50.0	60.2	69.3	71.3
PUTR	Height	27.6	28.3	40.6	42.9	42.5	41.7	45.7
Ada Co., Idaho	Crown	33.5	43.7	53.1	54.3	64.2	75.2	74.8
PUTR	Height	24.4	25.6	26.8	31.1	31.9	35.0	40.9
Carbon Co., Utah	Crown	32.7	47.2	51.2	53.5	58.3	73.2	77.6
PUTR	Height	26.0	31.1	40.6	36.6	41.3	42.5	52.4
Juab Co., Utah	Crown	35.4	52.0	59.1	56.3	63.4	73.6	83.5

[1/] COMES - Stansbury cliffrose; FAPA - Apache-plume; PUTR - Antelope bitterbrush

Antelope bitterbrush accessions that form stem layers are capable of spreading vegetatively and are not as dependent upon seed production for stand maintenance as are nonlayering forms. Layering forms are also generally more fire tolerant. The spreading crowns and extensive root systems add stability to sandy soils and steep slopes. New growth of these frequently low growing plants provides available forage for browsing animals, although they may be covered by snow during winter and early spring. Layering forms frequently produce less seed than upright forms, and seed collection is more difficult and time consuming.

Of the nine accessions studied, three of the antelope bitterbrush accessions exhibited stem layering (table 2). Of the Carbon County, Utah, plants, 36 percent formed stem layers. Native plants of this accession grow at a high elevation site with a short growing season. Under such conditions the plants may be dependent upon reproduction by vegetative spread. Nord (1965) observed that plants growing under similar conditions in northern California also produced numerous stem layers. Layering plants at Ada County, Idaho, are most numerous on steep cliffs or road cuts. Layering frequency is greater for Moffat County, Colo., plants growing on sand dunes (Wheeler, personal communication).

Mean annual height and crown measurements for seven of the accessions are reported in table 3. All accessions with the exception of the Ada County, Idaho, and Lassen County, Calif., antelope bitterbrush accessions exhibited slight to moderate amounts of dieback as a result of exposure to low temperatures during the winter of 1977-78, although only one Apache-plume plant was lost. The affected plants recovered during the succeeding growing season. Development of all plants from 1976 through 1979 was erratic and may have been the result of low temperatures during the winters of 1976-77 and 1978-79, low precipitation during the 1977 drought year, and low to moderate levels of grasshopper damage inflicted in 1978. More rapid growth was recorded during the 1980 and 1981 growing seasons.

Vegetative Phenology

An understanding of the timing of vegetative development in relation to flowering and seed production for each species is important in terms of management practices. Various management strategies and schedules may be designed to maximize seed or vegetative production and to control the growth form or size of the shrubs. Seed production and most vegetative growth of all four species studied occur in the spring and early summer during increasing temperatures and decreasing soil moisture levels. Timing of various phenological phases may vary from year to year depending upon climatic conditions. As a result, the use of observable phenological stages is preferable to the use of prescheduled dates in applying management techniques.

Initial leaf growth of each of the antelope bitterbrush accessions was observed between March 17 and 23 in 1979 and 1980 (table 4). Actual dates may have been slightly earlier as phenophases were recorded only weekly or biweekly. The first new leaf in most leaf fascicles expanded and attained mature size by mid-April at the time flower buds were beginning to develop. Although the Moffat County, Colo., accession initiated leaf growth slightly ahead of the others, differences in the timing and rate of leaf growth among accessions were minor.

Leader growth of all five antelope bitterbrush accessions was initiated during the first week of May in 1979 and 1980 at approximately the time when flower buds began to open (table 5). The initiation of leaf and leader growth occurred later in 1979 than in 1980. This pattern was observed in all nine accessions studied and may have resulted in response to the cooler early spring temperatures of 1979. The rate of leader growth remained low through May and increased in June and early July during fruit development and maturation. Growth rates diminished in July following

Table 4.--Phenological development of antelope and desert bitterbrush, Stansbury cliffrose, and Apache-plume accessions at the Boise Shrub Garden

Accession		Leaf growth initiated	First leaf expanded	Floral buds visible	Anthesis	Fruit development initiated	Leader growth initiated	Fruit mature
COMES[1/]	1979	April 26	May 18	May 14	June 5	June 13	May 12	July 20
Utah Co., Utah	1980	April 25	May 15	April 28	June 2	June 14	May 9	July 22
FAPA	1979	April 18	May 4	May 22	June 10	June 22	May 5	July 28
Sevier Co.,Utah	1980	April 16	May 2	May 5	May 25	June 3	April 28	July 30
PUGL	1979	April 26	May 18	April 28	May 24	May 29	May 18	July 18
Mono Co., Calif.	1980	April 23	May 15	April 21	May 17	June 5	May 14	July 22
PUGL	1979	April 26	May 18	April 28	May 25	May 28	May 20	July 18
Washington Co.,Utah	1980	April 23	May 15	April 21	May 21	June 4	May 14	July 21
PUTR	1979	March 21	April 18	April 21	May 14	May 24	May 5	July 7
Lassen Co., Calif.	1980	March 17	April 20	April 7	May 3	May 14	May 8	July 10
PUTR	1979	March 21	April 22	April 21	May 15	May 24	May 5	July 7
Moffat Co., Colo.	1980	March 17	April 23	April 14	May 4	May 12	May 8	July 10
PUTR	1979	March 21	April 18	April 24	May 13	May 24	May 5	July 7
Ada Co., Idaho	1980	March 17	April 15	April 22	May 6	May 16	May 8	July 10
PUTR	1979	March 21	April 18	April 21	May 14	May 25	May 5	July 7
Carbon Co., Utah	1980	March 20	April 20	April 14	May 4	May 11	May 8	July 10
PUTR	1979	March 21	April 22	April 21	May 16	May 26	May 5	July 7
Juab Co., Utah	1980	March 23	April 23	April 14	May 8	May 12	May 8	July 10

[1/] COMES - Stansbury cliffrose; FAPA - Apache-plume; PUGL - desert bitterbrush; PUTR - antelope bitterbrush

Table 5.--Leader growth of antelope and desert bitterbrush, Stansbury cliffrose, and Apache-plume accessions at the Boise Shrub Garden.

Accession	1979 1980	May 15 May 13	May 30 June 3	June 13 June 12	June 28 June 26	July 27 July 21	August 29 August 12	September 20
		------------	------------	------------	Inches	------------	------------	------------
COMES[1/]	1979	___	0.7	2.5	3.1	4.1	4.2	4.6
Utah Co., Utah	1980	___	1.5	3.4	6.2	6.4	6.4	
FAPA	1979	1.1	1.5	2.2	2.8	3.7	3.6	3.6
Sevier Co., Utah	1980	1.1	2.6	3.7	3.8	4.4	6.2	
PUGL	1979	___	1.7	2.3	2.7	3.5	3.5	3.6
Mono Co., Calif.	1980	___	1.0	1.6	2.0	4.6	4.6	
PUGL	1979	___	1.0	1.9	2.7	3.0	3.0	3.0
Washington Co, Utah	1980	___	0.9	1.5	1.9	3.0	3.0	
PUTR	1979	0.9	1.6	2.2	3.1	3.0	2.9	3.0
Lassen Co., Calif.	1980	0.9	1.5	1.5	4.6	5.1	5.2	
PUTR	1979	0.6	2.1	3.4	4.1	4.3	4.2	4.2
Moffat Co., Colo.	1980	0.4	1.4	2.5	2.8	3.7	3.7	
PUTR	1979	0.9	1.7	2.8	3.1	3.2	3.3	3.2
Ada Co., Idaho	1980	0.9	1.5	2.0	3.2	5.1	5.2	
PUTR	1979	0.7	1.7	2.5	3.0	3.1	3.0	2.8
Carbon Co., Utah	1980	1.0	1.5	1.5	2.1	2.4	2.4	
PUTR	1979	0.8	1.9	3.2	3.8	4.0	4.1	4.1
Juab Co., Utah	1980	0.7	1.5	1.9	3.5	4.8	5.2	

[1/] COMES - Stansbury cliffrose; FAPA - Apache-plume; PUGL - desert bitterbrush; PUTR - antelope bitterbrush

seed shatter. Minimal leader growth occurred during late summer and fall. Leaf fall has been observed for all five antelope bitterbrush accessions in response to moisture stress during mid-summer.

Leaf development of the Stansbury cliffrose and desert bitterbrush accessions started between April 23 and 26 each year. Expansion of the first new leaf in each fascicle was completed by mid-May in an average of 22 to 24 days. Leader development of both species followed a pattern similar to that for bitterbrush. In contrast to antelope bitterbrush, leaf fall during the late summer months was minimal for these accessions.

Leaf growth of Apache-plume started in mid-April, approximately 1 week earlier than that of the Stansbury cliffrose and desert bitterbrush accessions each year. The first leaf in each fascicle expanded rapidly and reached mature size within approximately 16 days of the time flower buds began to appear. Leader growth was initiated slightly in advance of flower bud appearance and continued into August.

Floral Phenology

Antelope Bitterbrush. Flowers of antelope bitterbrush are regular, perfect, and perigynous. They are pollinated by bees, wasps, and other insect species and are self-incompatible (Blauer and others 1975). The flowers are approximately 0.3 inch (8 mm) in diameter with showy, cream-colored deciduous petals. Normally, there is one or occasionally two pistils and a single series of approximately 25 stamens. The fruit is a cartilaginous, pubescent achene with a persistent style. Seeds are purplish-black.

Initiation and progression of the flowering sequence was very similar for each of the five antelope bitterbrush accessions in 1979 and in 1980 (tables 4 and 6). Floral buds appeared on all five between April 14 and 21 in 1979 and between April 7 and 14 in 1980. Bud formation may have been delayed in 1979 relative to 1980 as a result of cooler temperatures and greater precipitation during the winter and early spring of 1979. However, rainfall during flower and fruit development totaled 0.7 inches (1.8 cm) in 1979 and 5.0 inches (12.6 cm) in 1980. Seed of each accession was collected on July 6 in 1979 and July 10 in 1980.

Flower buds appeared nearly simultaneously on most shrubs within each accession. The solitary flower buds develop at the tips of short lateral spurs on second year or older wood. Buds appeared slightly earlier, and flowers and fruits developed more rapidly, on branches near the ground. Production of flower buds was somewhat limited both years as the shrubs had not reached full maturity. Bud production was greatest and most uniform among plants of the Moffat County, Colo., accession and most erratic for the Juab County, Utah, accession. However, over 90 percent of the shrubs in each accession produced at least moderate numbers of flowers.

No consistent differences among accessions were observed in the timing of flowering or fruit development. On all accessions, flower buds developed and remained closed for 2 to 3 weeks before opening for several days. Two nights of below-freezing temperatures -- 28°F (-2°C) on May 28 and 31°F (-1°C) on May 29 -- were recorded during or following flowering in 1979 while none was recorded in 1980. No frost damage to the developing fruit was observed.

Table 6.--Seed production and duration of flowering and fruiting phases for antelope bitterbrush, desert bitterbrush, Stansbury cliffrose, and Apache-plume accessions at the Boise Shrub Garden

Accession		Flowering period	Fruit development	Total	Percentage of fruit with multiple pistils	Normal and spotted mature seed
		Days				Percent
COMES[1/]	1979	30	37	67	100	87
Utah Co., Utah	1980	47	38	85	100	48
FAPA	1979	31	36	67	100	--
Sevier Co., Utah	1980	35	57	86	100	--
PUGL	1979	31	50	81	2	38
Mono Co., Calif.	1980	45	47	92	4	32
PUGL	1979	30	51	81	15	33
Washington Co, Utah	1980	44	47	91	28	59
PUTR	1979	33	44	77	2	67
Lassen Co., Calif.	1980	37	57	94	1	38
PUTR	1979	33	44	77	12	65
Moffat Co., Colo.	1980	28	59	87	15	55
PUTR	1979	30	44	74	11	56
Ada Co., Idaho	1980	24	55	79	7	47
PUTR	1979	34	43	77	17	21
Carbon Co., Utah	1980	27	60	87	20	39
PUTR	1979	35	42	77	9	66
Juab Co., Utah	1980	28	59	87	17	50

[1/] COMES - Stansbury cliffrose; FAPA - Apache-plume; PUGL - desert bitterbrush; PUTR - antelope bitterbrush

The period of fruit development for the five accessions differed between years. Fruit developed to maturity in 42 to 48 days in 1979 and in 57 to 60 days in 1980. Duration of the entire flower and fruit development ranged from 74 to 84 days in 1979 and from 87 to 94 days in 1980. Blaisdell (1958) reported flowering and fruit development of 66 days for antelope bitterbrush growing near Dubois, Idaho, at an elevation of 5,500 ft (1 676 m) while populations growing at elevations between 6,122 and 8,963 ft (1 866 and 2 732 m)) in Cache la Poudre Canyon, Colo., were found to require from 102 to 125 days (Colorado Game, Fish, and Parks Dept. 1965).

A number of insects are known to damage or destroy the seed of antelope bitterbrush (Ferguson and others 1963; Basile and Ferguson 1964; Basile and others 1964; Furniss 1975; Ferguson 1967). Significant reduction in potential seed production often results from insect infestation (table 6). Spotted seeds, which normally exhibit reduced germinability, were counted with normal seeds during the fruit development period because they could not be identified without being removed from the achene. Frequently observed seed predators in the area of the Boise Shrub Garden include a gall midge (*Mayetiola* spp.), a gelechiid (*Filatima sperryi* Clarke), thrips (*Frankliniella* spp.) and one or more species of stink bugs (*Chlorochroa* spp.).

Mature seeds dehisce quickly. Although seeds on individual accessions develop very uniformly, at least small percentage of seeds generally ripen and are disseminated prior to collection. Of the marked flowers, 38 to 55 percent were producing normal or spotted achenes on June 30, 1980. Much of this seed was lost just prior to collection because of high winds and rainstorms. By July 10, 1980, fully developed, mature seeds were collected from only 14 to 24 percent of the originally marked flower buds.

Plantings of antelope bitterbrush in seed orchards or common gardens may create situations that increase the susceptibility of the shrubs to attack by damaging insects, because dense, pure stands are available for invasion. Populations of predators and parasites of seed-damaging insects are limited by site maintenance practices (Van Epps and Furniss 1981). Inadequate knowledge of the biology and ecology of most of these seed damaging species is available to determine whether control practices can be effectively applied. Seed loss because of wind storms and insect damage emphasizes the need for careful selection of seed production sites and the need for development of appropriate cultural techniques for each species.

Desert Bitterbrush. Flowers of desert bitterbrush are morphologically similar to those of antelope bitterbrush, but are approximately 0.7 to 1.0 inches (18-25 cm) in diameter. They are insect-pollinated and self-incompatible (Blauer and others 975). Flowers normally produce three, or sometimes two, pistils. However, during the 1979 and 1980 seasons, an average of only 3 percent of the flowers of the Mono County, Calif., accession and 22 percent of the flowers of the Washington County, Utah, accession produced two pistils. No flowers with three pistils were observed. The achene is slightly smaller than that of antelope bitterbrush and has a more ronounced beak. Developing seeds are more yellow-green and mature seeds more eddish-purple than those of antelope bitterbrush.

Flower buds originate at the tips of spurs on second year and older growth. nly five shrubs of the California accession and 10 of the Utah accession produced ignificant numbers of floral buds in 1979. The number of shrubs to produce bundant flowers has increased annually since 1979, indicating that this species may e slower to reach maturity than antelope bitterbrush at the Boise location. The iming of flowering and fruit development stages was similar for both accessions table 4) and lagged from 1 to 2 weeks behind the same stages for antelope itterbrush. Flowering occurred after the last frost each year. Fruit development anged from 47 to 51 days for the two sources over the 2 years. Flowering and fruit development ranged from 81 to 92 days. Percentages of flowers to produce normal or spotted mature seed for the two accessions were quite low, ranging from 32 to 59 percent. The remaining seeds were all damaged or destroyed by insects.

Stansbury Cliffrose. Flowers of Stansbury cliffrose are regular, perigynous, and usually perfect. They are approximately 0.8 inches (2.0 cm) in diameter with 5 sepals, 5 petals, many stamens in 2 series and 4 to 12 pistils. The fragrant, pale yellow flowers are insect-pollinated and self-incompatible. The fruits are narrow, leathery achenes approximately 0.1 inches (0.3 cm) in length with long, white plumose styles. Approximately 90 percent of the flower buds are produced during the initial flowering period. Buds formed during this period are borne on short lateral spurs on second year or older wood. Stages of flowering and seed development lagged from 2 to 4 weeks behind those of antelope bitterbrush each year. Flowering occurred after the last frost each year. Fruit development required approximately 37 days each year. Flowering and fruit development was approximately 68 days in 1979 and 78 days in 1980.

Shrubs within this accession exhibited considerable variation in the number of flowers produced and seed maturation dates. Achenes mature fairly uniformly on individual shrubs from the initial group of floral buds. However, variation in seed maturation dates among shrubs necessitates almost daily seed collection as mature fruits dehisce quickly.

Additional flower buds form following initial flowering and throughout the summer, particularly following summer rains. These buds appear at the tips of leaders or spurs produced during the current growing season. Flowering at the Boise Shrub Garden has been observed well into October.

The only major type of damage observed on fruits of this accession involved the loss of all achenes from a single receptacle. This was probably insect caused because damage to the receptacle of some of these flowers was also observed. Also, the achenes of more than one flower on a branch were frequently removed while none of the flowers on nearby branches were affected. Initial damage was noted on June 15 in 1979 as flowering began. The percent of achenes lost by the time of fruit maturation was 13 percent in 1979 and 52 percent in 1980.

Apache-plume. The flowering habits of the Sevier County, Utah, Apache-plume accession have been described by Blauer and others (1975). Although some shrubs are dioecious, a majority are monoecious. Few flowers are fully bisexual. Pistillate flowers bear rudimentary, nonfunctional stamens, while staminate flowers bear rudimentary, nonfunctional pistils. Fruits are elongate achenes with plumose white and purplish styles.

Flower buds appeared later on Apache-plume than on the other species. Buds were first observed on May 22 in 1979 and on May 5 in 1980. Buds are formed on elongated peduncles originating from vegetative growth produced during the current season. They may be formed on lateral leaders, terminal leaders, or root sprouts. Buds may be solitary or several buds may develop in a small corymb. Flowering began about June 5 in 1979 and May 22 in 1980 following the last frosts of both growing seasons. The showy, white flowers are pollinated by a variety of Coleoptera and Hymenoptera. Unlike bitterbrush and Stansbury cliffrose, some Apache-plume flowers may be self-compatible (Blauer and others 1975).

Flower buds are produced continuously throughout the summer. Most buds develop over about 1 month following the appearance of the earliest buds. Consequently, the achenes do not ripen uniformly. The earliest buds produced mature fruit by July 28 in 1979 and by July 30 in 1980. The duration of the fruit development period for buds produced early in the season was 51 days in 1979 and 36 days in 1980. Flower and fruit development required 67 days in 1979 and 86 days in 1980. Additional flowers were produced through early October both years.

The Apache-plume, desert bitterbrush, and Stansbury cliffrose accessions have become established, have developed to maturity, and have produced viable seed crops at the Boise Shrub Garden, which is north of their native ranges. Plantings of each species at similar locations within 15 miles (33 km) of the Boise Shrub Garden have survived as long as 26 years, although no natural reproduction has been observed. An opportunity exists to extend the range of use for these species.

CONCLUSIONS

The nine shrub accessions exhibited characteristic growth forms, cycles of phenological development and levels of tolerance to environmental conditions. The wide range of variability existing within the four Rosaceous species examined provides a strong genetic base for breeding and selection programs. Increased use of shrubs in wildland revegetation projects has created a demand for site-adapted varieties exhibiting desired characteristics and suited to current planting and management techniques. Although numerous accessions of these species have been included in research and site improvement plantings, commercial varieties are not yet available.

The five antelope bitterbrush accessions established readily and exhibited a wide variation in growth habits and seed production capabilities, although timing of their phenological phases was quite similar. Milder climatic conditions and a relatively long frost free season at the Boise Shrub Garden compared to the other seed source locations may have contributed to their success. The loss of seed as a result of wind storms and insect damage serves to emphasize the need for care in the selection of seed production sites and the requirement for the development of appropriate cultural techniques for each species.

The Apache-plume, desert bitterbrush, and Stansbury cliffrose accessions have become established and developed to maturity at the Boise Shrub Garden, which is located north of their native ranges. Plantings of each of these species at similar locations within 15 miles (9 km) of the Boise Shrub Garden have survived for as long as 26 years, although no natural reproduction has been observed. An opportunity exists to extend the range of use for these species.

PUBLICATIONS CITED

Alderfer, J. M. A taxonomic study of bitterbrush (Purshia tridentata [Pursh] DC.) in Oregon. Corvallis, OR: Oregon State University; 1977. 197 p. Thesis.

Basile, J. V.; Ferguson, R. B. Say stink bug destroys bitterbrush seed. J. Range Manage. 17(3): 153-154; 1964.

Basile, J. V.; Ferguson, R. B.; Furniss, M. M. Six-legged seed eaters. Idaho Wildlife Review 17(3): 5-7; 1964.

Blaisdell, J. P. Seasonal development and yield of native plants on the Upper Snake River plains and their relation to certain climatic factors. Tech. Bull. No. 1190. Washington, DC: U.S. Department of Agriculture; 1958. 68 p.

Blauer, A. C.; Plummer, A. P.; McArthur, E. D.; Stevens, R.; Giunta, B. C. Characteristics and hybridization of important intermountain shrubs. I. Rose family. Res. Pap. INT-169. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1975. 35 p.

Colorado Game, Fish, and Parks Department. Game research report. Part three. Federal aid project W-105-R. 1965: 327-501.

Everett, R. L. Use of containerized shrubs for revegetating arid roadcuts. Reclamation Review 3: 33-40; 1980.

Everett, R. L.; Tueller, P. T.; Davis, J. B.; Brunner, A. D. Plant phenology in galleta-shadscale and galleta-sagebrush associations. J. Range Manage. 33(6): 446-450; 1980.

Ferguson, R. B. Relative germination of spotted and nonspotted bitterbrush seed. J. Range Manage. 20(5): 330-331; 1967.

Ferguson, R. B.; Furniss, M. M.; Basile, J. V. Insects destructive to bitterbrush flowers and seeds in southwestern Idaho. J. Econ. Entomol. 56(4): 459-462; 1963.

Furniss, M. M.; Barr, W. F. Insects affecting important native shrubs of the northwestern United States. Gen. Tech. Rep. INT-19. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1975. 64 p.

Giunta, B. C.; Stevens, R.; Jorgensen, K. R.; Plummer, A. P. Antelope bitterbrush - an important wildland shrub. Pub. No. 78-12. Salt Lake City, UT: Utah Division of Wildlife Resources; 1978. 48 p.

Holmgren, R. C. A comparison of browse species for revegetation of big-game winter ranges in southwestern Idaho. Res. Pap. No. 33. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1954. 12 p.

Holmgren, R. C. Competition between annuals and young bitterbrush (Purshia tridentata) in Idaho. Ecology 37(2): 370-377; 1956.

Hopp, R. J.; Blair, B. O. I. Development of networks and preliminary results. In: Plant phenology in eastern and central North America. Bull. 677. Burlington, VT: Vermont Agricultural Experiment Station; 1973: 1-20.

Hormay, A. L. Bitterbrush in California. Res. Note No. 34. Berkeley, CA: U.S. Department of Agriculture, Forest Service, California Forest and Range Experiment Station; 1943. 13 p.

McArthur, E. D.; Plummer, A. P.; Van Epps, G. A.; Freeman, D. C.; Jorgensen, K. R. Producing fourwing saltbush seed in seed orchards. In: Proceedings of the First International Rangeland Congress; Denver, CO: Soc. of Range Management; 1978: 406-410.

Menke, J. W.; Trlica, M. J. Carbohydrate reserves, phenology and growth cycles of nine Colorado range species. J. Range Manage. 34(4): 269-277; 1981.

Monsen, S. B. Selecting plants to rehabilitate disturbed areas. Improved range plants. In: Campbell, R. S.; Herbel, C. H., eds. Range symposium, series 1; Denver, CO: Soc. of Range Management; 1975: 76-90.

Monsen, S. B.; Plummer, A. P. Plants and treatment of disturbed sites in the intermountain area. In: Wright, R. A., ed. The reclamation of disturbed arid lands, Albuquerque, NM: University New Mexico Press; 1978: 155-173.

Nord, E. A. Autecology of bitterbrush in California. Ecol. Monogr. 35(3): 307-334; 1965.

Plummer, A. P.; Christensen, D. R.; Monsen, S. B. Restoring big-game range in Utah. Publ. 68-3. Ephraim, UT: Utah Division Fish and Game; 1968. 183 p.

Plummer, A. P.; Hull, A. C., Jr.; Stewart, G.; Robertson, J. H. Seeding rangelands in Utah, Nevada, southern Idaho, and western Wyoming. Agric. Hand. 71, Washington, DC: U.S. Department of Agriculture; 1955. 73 p.

Stutz, H. C. Rapid evolution in western shrubs. Utah Science 35: 16-20, 33; 1974.

Stutz, H. C.; Thomas, L. K. Hybridization and introgression in Cowania and Purshia. Evolution, 18: 183-195; 1964.

Tiedemann, A. R.; Klock, G. O.; Mason, L. L.; Sears, D. E. Shrub plantings for erosion control in eastern Washington - progress and research needs. Res. Note PNW-279. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Experiment Station; 1976. 11 p.

Van Epps, G. A. Shrub seed production - a potential enterprise. Utah Science 35(1): 21-23; 1974.

Van Epps, G. A.; Furniss, M. M. Walnut spanworm: a new defoliator of Utah's bitterbrush. Utah Science 42(2): 79-85; 1981.

West, N. E.; Wein, R. W. A plant phenological index technique. BioScience 20: 116-117; 1971.

SEED PHYSIOLOGY OF ANTELOPE BITTERBRUSH AND RELATED SPECIES[1]

James A. Young and Raymond A. Evans[2]

ABSTRACT

Dormancy of the seeds of antelope bitterbrush (Purshia tridentata [Pursh] DC), desert bitterbrush (P. glandulosa Curran), and cliffrose (Cowania mexicana var. stansburiana [Torr.] Jeps.) seeds is a major factor limiting successful artificial revegetation with these species. Dormancy is broken under natural conditions by cool-moist stratification. To enhance germination before artificially seeding these shrubs, land managers can stratify seeds or treat them with hydrogen peroxide. Even with optimum enhancement, the germination will rarely exceed 60 percent.

INTRODUCTION

The closely related members of the Rosaceae family, desert and antelope bitterbrush and cliffrose, are valuable browse species on western rangelands. In many areas, communities of these plants have deteriorated, and land managers have attempted to revegetate rangelands by planting seeds of these species.

One major hindrance to seeding all three species is dormancy of the seed. Many land managers and scientists have recognized the problem, and as a result, the seed ecology of antelope bitterbrush has been subject to research for 45 years. A bibliography of antelope bitterbrush literature, done over a decade ago, lists over 200 citations, many of which mention or are solely concerned with germination and seedbed ecology problems (Basile 1967). A more recent annotated bibliography (Clark and Britton 1979) also stresses the importance of seed and seedbed ecology for bitterbrush. The germination and establishment problems probably are as important to the regeneration of desert bitterbrush and cliffrose as they have been demonstrated for antelope bitterbrush, but much less research has been devoted to these species.

NATURE OF DORMANCY

Conflicting terminology has been used to describe the fruits of bitterbrush; for clarification, we will define the terms we use before proceeding with a review of the nature of dormancy. The perfect yellow flowers of antelope bitterbrush are borne singly at the end of short lateral leafy spurs. The fruit is an oblong achene about 0.13 to 0.5 inches (6 to 12 mm) long. The achene consists of the embryo or miniature plant, radicle, hypocotyl, and cotyledons covered by the seedcoat and pericarp. The pericarp, or ripened wall of the ovary, is soft and bright red when the seed is forming, but becomes very dark at maturity. The achene is dry and flinty when mature, and we will refer to it as a seed. When the seed of antelope bitterbrush is mature, it falls from the plant with a papery covering composed of remnant flower parts and tipped with a remnant of the style. Desert bitterbrush seeds have the same covering except the beaked style remnant tends to be more elongated. The seeds of cliffrose are completely enclosed in a thickened, funnelform remnant of flower parts and are tipped by long, feathery styles. Before entering commerce, the papery covering of bitterbrush seeds is normally rubbed free of the seed. The thickened covering of cliffrose seeds cannot be mechanically removed without damaging the seed. When we refer to a cliffrose "seed," the entire assemblage is included. Generally, when sold in commerce, the seeds of cliffrose have the feather style removed.

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When the embryos of antelope bitterbrush seeds are dissected from the achenes, the embryos will germinate, indicating the dormancy is controlled by factors associated with the seedcoat and/or pericarp. Embryo dissection has been used as a quick viability check for antelope bitterbrush seeds (Nord 1956).

The seeds of antelpe bitterbrush are largely dormant at harvest. Usually 5 to 20 percent of a seed lot will germinate without enhancement. Germination of antelope bitterbrush seeds is greatly enhanced by cool-moist stratification. This treatment simply consists of placing the seeds in a moist environment at a temperature too cold to allow germination. The term "stratification" originated from the forestry practice of placing seeds between layers of peat moss to form a stratified bed for winter chilling. The usual rationale given for germination enhancement from stratification is that the cool-moist period allows sufficient oxygen to reach the enbryo to allow germination. We will expand on this concept in a later section on stratification.

Dormant antelope bitterbrush seeds do imbibe water. The seedcoat and pericarp do not interefere with moisture inbibition as is the case with hard-seeded legumes.

In addition to stratification, thiourea treatment can remove the inhibition to germination of antelope bitterbrush seeds (Pearson 1956). Thiourea belongs to a class of compounds called sulfydryls, a number of which have a markedly stimulatory effect on dormant seeds (Roberts 1973). In solution, thiourea is in equilibrium with the iso form: $NH_2\ CSNH_2 \quad NH_2\ C(SH){:}NH$. One peculiarity of these compounds is that they can have an extremely narrow concentration range for optimum activity. Thiourea enhancement of antelope bitterbrush germination seems to be an ideal solution to dormancy as far as land managers are concerned. After soaking the seeds in the thiourea solution, they are dried. When the dried seeds are rewet after planting in the field, the thiourea is effective in enhancing germination. In contrast, once antelope bitterbrush seeds, or those of most other species, are stratified, the seeds must be planted immediately for the germination enhancement to be effective. If the stratified seeds are dried, not only is the advantage gained by stratification lost, but the seeds become nonviable. Three problems are associated with the use of thiourea-treated bitterbrush seeds: (1) the treatment has never been as effective in producing established stands in the field as laboratory results would indicate, (2) thiourea is labeled as a highly toxic substance to humans, and (3) thiourea-treated seeds must be seeded in the spring. Very little information is published about the response of cliffrose and desert bitterbrush seeds to thiourea, but in one trial, cliffrose seed germination was enhanced by thiourea treatment (Alexander and others 1974).

Antelope bitterbrush seeds have increased germination when treated with solutions of hydrogen peroxide (Everett and Meeuwig 1975). Hydrogen peroxide is a compound that has been shown to enhance germination of seeds of numerous species (Crocker and Barton 1953). Another major group of compounds that have been shown to enhance germination is the gibberellic acids. Gibberellin has been used to substitute for the stratification requirements of antelope bitterbrush seeds (McConnell 1960).

Many land managers who have worked with seeding of antelope bitterbrush in the field believe seeds stored at cool and cold temperatures for a year germinate better than freshly harvested seeds. This response would be similar to an after-ripening requirement although such requirements usually do not respond to storage temperatures.

In summary, the seedcoat and/or pericarp of antelope bitterbrush seeds interfere with the germination of these seeds. This interference can be overcome by cool-moist stratification or by treatment with various chemicals, all of which have been shown to influence the pentose phosphate pathway of dormancy (Roberts 1973).

GERMINATION PROFILES

In a recent publication we developed germination profiles for antelope and desert bitterbrush and cliffrose seeds (Young and Evans 1981). We compared four basic germination treatments for each species: (1) control with no treatment before the seeds were incubated, (2) thiourea soaking before incubation, (3) hydrogen peroxide soaking before incubation, and (4) cool-moist stratification before incubation. The details of each treatment are given in subsections.

In all treatments, four replications of 100 seeds were used. Unless otherwise specified, we collected seeds in northern Nevada for antelope bitterbrush or purchased seeds from southwestern Utah for desert bitterbrush and cliffrose during the summer that they were produced and began testing in October of the same year. Seeds were stored in the laboratory in paper bags before testing. Usually, the seeds were hand threshed to avoid injury. The papery flower parts that persist around the achenes of antelope and desert bitterbrush were removed. The indurate portion of the funnelform flower of cliffrose that persists around the achene was not removed. Seeds were placed on a single thickness of germination paper in petri dishes and kept moist with tap water. Seeds were considered germinated when the radicle emerged 0.25 inches (0.5cm). The seeds were incubated in dark germinators.

Control Profiles

To develop profiles of the germination of seeds of each species in relation to temperature, we incubated the seeds at 55 constant and alternating temperature regimes. Constant regimes consisted of 0°, 2°, 5°, and then at 5° increments through 40°C. Alternating regimes consisted of 16 hours at each constant temperature alternating with 8 hours at each higher temperature in the profile daily. For example, 0°C alternated with 2°, 5°, 10°, 15°, 20°, 25°, 30°, 35°, and 40°C while 35°C alternated with 40°C only. Seeds were incubated for 4 weeks with counts made at 1, 2, and 4 weeks. Seeds were considered germinated when the radicle emerged 0.25 inches (0.5 cm).

The effects of constant and alternating temperatures on each species in terms of germination percentage were statistically analyzed using a quadratic response surface. This quadratic response surface was composed of a series of regression equations, one for each cold period (16 hours) temperature through the series of warm period temperatures (8 hours) with calculated values and their confidence limits (Evans and others 1982).

Thiourea

WARNING! Before considering any seed treatment with thiourea, remember it is a highly toxic chemical. The regulations of most public land management agencies prohibit the use of this material as a dormancy breaker.

We soaked the seeds of all three species in a 3 percent solution of thiourea for 30 minutes, allowed the seeds to dry, and then incubated them at the standard 55 constant and alternating temperatures used for germination profiles.

Hydrogen Peroxide

The seeds of all three species were pretreated by soaking for 6 hours in 1 percent hydrogen peroxide following the procedures of Everett and Meeuwig (1975).

RESULTS: GERMINATION PROFILES

Control

For the 55 temperature regimes of the standard germination profile, seeds of antelope bitterbrush averaged only 16 percent germination, but germinated significantly better (P = 0.01) than the other two species (table 1). Germination was very low for the seeds of cliffrose and desert bitterbrush.

Seeds of antelope bitterbrush germinated at a wide range of constant and alternating temperatures without pretreatment. Some germination occurred at 87 percent of the regimes tested (table 1). Optimum temperature regimes for germination were spread over a wide range of warm period temperatures from 15° to 30°C. Except for 10°/25°C (10°C for 16 hours/25°C for 8 hours in each 24-hour period), the optima occurred at 0° to 5°C cold period temperatures which, as will be seen in a later section, are the ideal temperatures for stratification of antelope bitterbrush seeds. Essentially, during the 4-week incubation period, antelope bitterbrush seeds were partially self-stratifying themselves at these incubation temperatures. Partitioning the profiles into percentiles indicated that 51 percent of the regimes had germination from 10 to 25 percent and 27 percent had germination below 10 percent (table 1).

The germination profile for desert bitterbrush seeds was considerably different with no evidence of self-stratification. There was no germination at 0°C or any temperature regime that alternated with 0°C. The optimum regimes were restricted to constant temperatures of 5° through 20°C except for 10°/15°C. Germination occurred at only 51 percent of the regimes tested, and an overwhelming 95 percent of the regimes had germination below 10 percent. Overall, germination of desert bitterbrush without pretreatment was very low.

Germination of cliffrose seeds was low at all temperatures, and some germination occurred at only 60 percent of the temperatures tested. The optimum temperature regimes for germination were scattered over a wide range and accounted for 27 percent of the possible regimes (table 1). Some of the optima occurred in the self-stratifying range of 0°/25°, 2°/30°, and 5°/20° through 5°/30°C, but others were the warm regimes of 20°/25° to 20°/30°C. On a percentile basis, 67 percent of the regimes had germination below 10 percent.

Thiourea

The soaking period we found to give optimum enhancement of germination for all three species and was used for the profiles was 30 minutes in a 3 percent solution of thiourea (Young and Evans 1981). This is a much longer soaking time than was originally proposed by Pearson (1956). He found that long-duration soaking inhibited germination. Antelope bitterbrush seeds have been shown to be sensitive to the temperature of the soaking solution with high soaking temperatures reducing subsequent germination (Neal and Sanderson 1975). It may be that high soaking temperatures led Pearson to discount the value of longer duration thiourea treatments in enhancing germination. The value of longer duration soaking in thiourea solutions was originally pointed out by the late Eamor Nord (personal communication).

Table 1.--Comparison of parameters synthesized from quadratic response surface for germination profiles for antelope bitterbrush, desert bitterbrush, and cliffrose seeds without treatment before incubation. See Young and Evans (1981) for complete profiles.

Parameters	Cliffrose	Desert bitterbrush	Antelope bitterbrush
		Percent	
Regimes with some germination	60	51	87
Mean germination	9	5	19
Regimes with optimum germination	27	11	22
Mean of optima	13	8	30
Germination percentiles:			
10	67	95	27
10-25	33	5	51
26-50	0	0	22
51-75	0	0	0
76-90	0	0	0
90	0	0	0

For the overall mean germination at the 55 constant and alternating temperature regimes tested, antelope bitterbrush seeds had significantly higher ($P = 0.01$) germination than the other species. Cliffrose seeds were intermediate in germination, and desert bitterbrush germination profiles had the lowest average germination.

Seeds of antelope bitterbrush germinated at all temperatures tested except 0°/0°, 35°/40°, and 40°/40°C after being treated with thiourea. The mean germination of regimes with some germination was 46 percent (table 2). Optimum temperature regimes occurred at 18 percent of the temperatures tested with an average germination of 65 percent. The optima occurred at temperatures from 10° to

25°C alternating with 2° to 10°C. Based on a percentile breakdown, 49 percent of the regimes produced germination between 51 and 75 percent, and only 11 percent had germination below 10 percent.

Seeds of desert bitterbrush germinated at 85 percent of the temperature regimes tested after treatment with thiourea (table 2). Besides 0°/0°C, desert bitterbrush seeds failed to germinate at 35°/35° or 40/40°C and most of the temperature regimes that alternated with 40°C. Optimum regimes for germination were clustered around 15°/25°C and accounted for 15 percent of all regimes, with a mean germination of 43 percent. Based on percentile, 26 percent of the temperature regimes produced germination below 10 percent.

After treatment with thiourea, cliffrose seeds germinated at 93 percent of the temperature regimes tested (table 2). Only the very cold and extremely warm regimes failed to support some germination. Optima constituted 16 percent of the regimes in a tight cluster in the 20° and 25°C warm period temperatures, alternating with 2° and 15°C cold period temperatures. The mean germination at the optimum regimes was 66 percent. Based on percentiles, 29 percent of the regimes produced germination between 51 and 75 percent, and 15 percent had germination below 10 percent.

Table 2.--Comparison of parameters synthesized from quadratic response surfaces for germination profiles for antelope bitterbrush, desert bitterbrush, and cliffrose seeds soaked in a 3 percent solution of thiourea for 30 min. before incubation. See Young and Evans (1981) for complete profiles.

Parameters	Cliffrose	Desert bitterbrush	Antelope bitterbrush
		Percent	
Regimes with some germination	93	85	95
Mean germination	38	26	46
Regimes with optimum germination	16	15	18
Mean of optima	66	43	65
Germination percentiles:			
10	15	26	11
10-25	18	27	7
26-50	38	47	33
51-75	29	0	49
76-90	0	0	0
90	0	0	0

Stratification

Stratification of bitterbrush is intricately related to temperature and time. Hormay (1943) reported that the stratification requirements for bitterbrush seeds were 5 to 8 weeks at 0° to 5°C. This temperature range is supported by our investigation, but our results indicate that the duration can be shortened (Young and Evans 1976). More importantly, excessively long stratification can reduce subsequent germination.

The usual recommended stratification period for antelope bitterbrush is 2 to 3 months (U.S. Department of Agriculture, Forest Service 1948). Petzold (as cited by Deischman and others 1974) found that short stratification periods of as little as 2 weeks gave adequate germination.

We have determined that osmotic and matric potentials of the soil, water, and fluctuations in seedbed temperatures can dramatically influence the degree of germination enhancement received from stratification.

No one knows for certain what is the mode of action for stratification enhancing seed germination; however, we (Young and Evans 1976) previously suggested a possibility based on the research of the French seed physiologist, Come (1967).

Embryos require very little 0_2 in the environment to germinate. The lower temperature, the less 0_2 is needed (Come and Tissaoui 1972). The higher the temperature, the greater the 0_2 requirement of the embryo, but the quantity of available 0_2 decreases because at higher temperature it is less soluble and phenolic substances chemically react with the 0_2 before it reaches the embryo. At 2°C, about 14 p/m 0_2 are soluble in water, but only 10 p/m are soluble at 15°C (Streeter 1935). Because low temperatures increase solubility of 0_2 in water and reduce both the requirements for it and the fixing capacity of the seedcoat, stratification enhances germination of antelope bitterbrush seeds.

Mean germination of desert bitterbrush (38 percent) at 55 constant and alternating temperatures after 2 weeks stratification at 5°C was significantly higher (P = 0.01) than that for the other species. The mean germination of cliffrose seeds (39 percent) was intermediate and that for antelope bitterbrush seeds (31 percent) was lowest.

The quadratic response surface for antelope bitterbrush germination reveals some germination at 91 percent of the temperature regimes tested. The optimum temperature regimes for germination were loosely clustered around 5°/15°C encompassing 23 percent of the temperature regimes with an average germination of 52 percent. Partitioning the profile into percentiles shows that 52 percent of the temperature regimes produced germination from 26 to 50 percent (table 3). Only 15 percent of the regimes produced germination greater than 50 percent. On the other end of the germination spectrum, 15 percent of the regimes produced germination of less than 10 percent.

Table 3.--Comparison of parameters synthesized from quadratic response surfaces of germination profiles for antelope bitterbrush, desert bitterbrush, and cliffrose seeds after cool, moist stratification. See Young and Evans (1981) for complete germination profiles.

Parameters	Cliffrose	Desert bitterbrush	Antelope bitterbrush
		Percent	
Regimes with some germination	96	80	91
Mean germination	37	50	36
Regimes with optimum germination	15	11	23
Mean of optima	55	72	52
Germination percentiles:			
10	11	22	15
10-25	16	9	18
26-50	51	36	52
51-75	22	31	15
76-90	0	2	0
90	0	0	0

The quadratic response surface for germination of seeds of desert bitterbrush showed a lower number of temperature regimes that supported some germination than antelope bitterbrush, but a higher average germination (table 3). Desert bitterbrush seeds failed to germinate at 40°C or colder temperatures alternating with 40°C except for 15°/40°C. Optimum temperature regimes were tightly clustered at 10°/10°, 10°/15°, 10°/20°, 15°/15°, 15°/20°, and 20°/20°C. The mean of the optima was 72 percent. Partitioned into percentiles, 67 percent of the temperature regimes supported germination between 26 and 75 percent. The failure to germinate at most 40°C temperatures was reflected in the 22 percent of the regimes that produced germination below 10 percent.

Seeds of cliffrose had some germination at all temperature regimes except 0°/0° or 0°/2°C. The mean germination of the 52 regimes that produced some germination was 37 percent (table 3). The temperature regimes that produced optimum germination were clustered around 5°/25°C and extended to 2°/25°C. The mean of the optima was 55 percent. On a percentile basis, 51 percent of the temperature regimes produced germination in the 26- to 50-percent range and only 11 percent were below 10 percent.

Hydrogen Peroxide

The overall mean germination of antelope bitterbrush seeds (21 percent), pretreated with 1-percent H_2O_2 for 6 hours, was significantly higher ($P = 0.01$) han that for the other two species. Desert bitterbrush seeds had intermediate ermination (19 percent), and the mean germination of cliffrose seeds (9 percent) as lower.

The quadratic response surface for percent germination of H_2O_2 treated seeds reveals some germination at 85 percent of the temperature regimes tested with a mean germination of 26 percent (table 4). The optimum temperatures for germination clustered around 10°/10°, 10°/15°, and 10°/20°C with a mean of 49 percent. Dividing the profile into percentiles resulted in 47 percent of the profiles having germination from 26 to 50 percent. A large proportion of regimes, 29 percent, supported germination only from 0 to less than 10 percent.

A quadratic response surface for percent germination of desert bitterbrush seeds treated with H_2O_2 was similar to that of antelope bitterbrush (table 4). Some germination occurred at 87 percent of the 55 temperature regimes tested.

Mean germination of the regimes with some germination was 13 percent. The number of regimes with optimum germination was 13 percent of the total, the same as for antelope bitterbrush. The mean of the optima was 37 percent. The optimum regimes were clustered around 10°/20°, 10°/25°, and 10°/30°C or slightly higher warm period temperatures than for antelope bitterbrush. The percentile distribution of germination and temperature regimes for desert bitterbrush germination was practically identical to those for antelope bitterbrush seeds.

The quadratic response surface for percent germination of cliffrose seeds treated with H_2O_2 reveals a limited germination response (table 4). Germination occurred at 62 percent of the temperatures tested with a mean of 14 percent. The optimum temperature regimes for germination spread over a relatively wide range of temperatures (20 percent of the total) from 10°/10° through 20°/25°C. The lack of germination enhancement of cliffrose seeds with H_2O_2 treatments is illustrated by the 62 percent of the temperature regimes with less than 10-percent germination.

Table 4.--Comparison of parameters synthesized from quadratic response of germination profiles for antelope bitterbrush, desert bitterbrush, and cliffrose seeds treated with hydrogen peroxide. See Young and Evans (1981) for complete profiles.

Parameters	Cliffrose	Desert bitterbrush	Antelope bitterbrush
		Percent	
Regimes with some germination	62	87	85
Mean germination	14	23	26
Regimes with optimum germination	20	13	15
Mean of optima	25	37	49
Germination percentiles:			
10	62	27	29
11-25	31	31	24
26-50	7	42	47
51-75	0	0	0
76-90	0	0	0
90	0	0	0

DISCUSSION

Enough antelope bitterbrush seeds germinate without germination enhancement to suggest that through hybridization and selection, plant breeders might be able to greatly increase germination and reduce the strict stratification requirements. This is a long-term project, but certainly should be included in programs to shift seed collection of these species from native stands to seed orchards.

There are many constraints on the seeding of moist, stratified seeds, both from a mechanical handling standpoint and from the biological requirements. Essentially, one can only seed prestratified seeds in a seedbed that is conducive to continued germination. This means that drilling would be limited to short periods of time when temperature and moisture conditions are satisfactory in seedbeds. These seedbed conditions would have to be predicted because of the time required for stratification and the loss of viability with prolonged stratification. Despite all these drawbacks, stratification is the only germination enhancement technique available for many species. Development of drills to handle moist seeds should continue.

If effective rodent repellents could be developed, fall seeding of bitterbrush and cliffrose seeds probably would be the most desirable alternative. Pesticide restrictions have greatly limited the potential materials for use as repellents, and one should remember that any time a chemical is placed in close proximity to a seed, there is a distinct possibility of influencing germination. Equally important with the development of repellent is the continued study of rodent-seed ecology. The complex interaction of rodents and antelope bitterbrush seeds is well known. We assume that a similar relation exists for desert bitterbrush and cliffrose seeds under natural conditions. An unexplored possibility for enhancing regeneration of these species is to manipulate rodent populations or artificially feeding seeds into the rodent caching cycle with or without subsequent control of rodents.

Hydrogen peroxide offers an alternative method of enhancing germination of the bitterbrush species. Stratification gives a better enhancement of germination than hydrogen peroxide, especially for cliffrose seeds. The advantages for hydrogen peroxide are a shorter treatment time is required and the seeds can be dried. If we understood the nature of germination enhancement from hydrogen peroxide treatments, it might be possible to perfect the methodology to increase germination enhancement.

Practically, thiourea, the ideal germination enhancer for bitterbrush seeds, is a dead issue. Virtually all State and Federal land management agencies have outlawed the use of this material.

In the final analysis, we know a great deal about the germination of bitterbrush and cliffrose seeds. We also know that a great deal of work is required to develop this knowledge into a form that adequately answers the problems land managers face in trying to revegetate rangelands with these species.

PUBLICATIONS CITED

Alexander, R. R.; K. Jorgensen; and Plummer, A. P. *Cowania mexicana* var. *stransburiana* (Torr.) Jepsen, cliffrose. In Schopmeyer, C.S.(tech. coord). Seeds of woody plants in the United States. Agric. Handbook 450. U.S. Department of Agriculture, Washington, D.C. 1974. 353-355.

Basile, J. V. An annotated bibliography of bitterbrush [*Purshia tridentata* (Pursh) DC]. Res. Pap. No. 44. U.S. Department of Agriculture, Forest Service, Ogden, UT. Intermountain Forest and Range Experiment Station, 1967. 27p.

Clark, R. G., and C. M. Britton. A bibliography of bitterbrush annotated from 1967-1978. Corvallis, OR: Oregon Agricultural Experiment Station, Bull. 690, 1979. 18 p.

Come, D. L'inhibition de germination des graines de Pommier (Pirus nalus L.) non dormantes. Role possible des phenols tegumentaltes. Botanique et Biologie Vegetale 8, Annales des Sciences Naturelles. 1967. 371-478.

Come, D., and T. Tissaoui. Interrelated effect of inhibition, temperature, and oxygen on seed germination. In Heydecker, W., ed. Seed ecology, Pennsylvania State University Press, University Park, PA. 1972. 15-168.

Crocker, W., and L. V. Barton. Pysiology of seeds. Chronica Botanica Co., Waltham, MA. 1953. 267 p.

Deitschman, G. H.; Jorgensen, K. R.; Plummer, A. P. Purshia. In C.S. Schopmeyer, tech. coord., Seeds of woody plants in the United States. Agric. Handbook 450. U.S. Department of Agriculture 1974. 686-688.

Evans, R. A.; Easi, D. A.; Book, D. N.; Young, J. A. Quadratic response surface analysis of seed germination trials. Weed Science 30:411-416. 1982.

Everett, R. L., and R. O. Meeuwig. Hydrogen peroxide and thiourea treatment of bitterbrush seed. Res. Note No. 196. Ogden, UT; Intermountain Forest and Range Experiment Station. U.S Department of Agriculture, Forest Service. 1975. 6 p.

Hormay, A. L. Bitterbrush in California. Res. Note No. 9. Berkeley, CA: California Forest and Range Experiment Station. U.S. Department of Agriculture, Forest Service. 1943. 13 p.

McConnell, B. R. Effect of gibberellic acid and cold treatments on the germination of bitterbrush seed. Res. Note. 187. Portland, OR: Pacific Northwest Forest and Range Experiment Station. U.S. Department of Agriculture, Forest Service. 1960. 4 p.

Nea, D. L., and H. R. Sanderson. Thiourea solution temperature and bitterbrush germination and seedling growth. J. Range Manage. 25:421-423. 1975.

Nord, E. C. Quick testing bitterbrush seed viability. J. Range Manage. 9:193-194. 1956.

Pearson, B. O. Bitterbrush (Purshia tridentata) seed dormancy broken with thiourea. J. Range Manage 10:41-42. 1956.

Roberts, E. H. Oxidative processes and the control of seed germination. In Heydecker, H., ed., Seed ecology. Univeristy Park, PA. Pennsylvania State University Press, 1973. 189-218.

Streeter, H. W. Stream pollution. J. Sewage Works 7:355. 1935.

U.S. Deapartment of Agriculture, Forest Service. Wood-plant seed manual. Miscellaneous Publication No. 654. U.S. Department of Agriculture. 1948. 416 p.

Young, J. A., and R. A. Evans. Stratification of bitterbrush seeds. J. of Range Manage. 29:421-425. 1976.

Young, J. A., R. A. Evans. 1981. Germination of antelope bitterbrush, desert bitterbrush and cliffrose. Agric. Res. Results AAR-W017. U.S. Department of Agriculture, Sci. and Ed. Adm. 1981. 39 p.

Section 3. Successional Relationships

ANTELOPE BITTERBRUSH SEEDLING ESTABLISHMENT FOLLOWING PRESCRIBED BURNING IN THE PUMICE ZONE OF THE SOUTHERN CASCADE MOUNTAINS[1]

Robert E. Martin[2]

ABSTRACT

Antelope bitterbrush (Purshia tridentata) seedling establishment was surveyed on 21 units two to eight growing seasons after burning. Bitterbrush seedlings occupied from one-quarter to five times as many of the plots as did old plants, and regeneration was related to seasons since burn, site quality, and livestock grazing. Records were kept of bitterbrush seedlings, seedling groups, stems per group, and height and diameter growth.

INTRODUCTION

Antelope bitterbrush (Purshia tridentata) is one of the most important browse plants for big game in the Northwest. Because it is often detrimental to bitterbrush, fire has been restricted in big game winter range areas. However, in considering the amount of bitterbrush in many areas, we must question the presumed detrimental effect of fire. Fire was a frequent visitor to much of the pine bitterbrush type in the southern Cascade Mountains. Weaver (1959), Soeriaatmadja (1966), Martin and Johnson (1979), and studies by the Bend Silviculture Laboratory[3] show that fire in this area was as frequent as once every 5 to 15 years, with the period between fires increasing as we go to higher, wetter, and cooler sites. Some of the areas in this study were clearcut and burned in the 1920's, yet bitterbrush is the dominant understory plant in the young pine stands.

Because of the predominance of bitterbrush in these stands, it must have effective mechanisms for regeneration after fire (Driver and others 1980). Regeneration might come from seedlings or sprouts, and many factors might affect both means of reproduction (Martin and Driver, in this proceedings).

This study was conducted to evaluate regeneration, particularly seedlings, on 21 prescribed burns. The purpose of the study was to evaluate reestablishment of bitterbrush on prescribed fires the first few years after burning by answering the following questions: Is there a relationship between percent stocking and time? How regular is the establishment over time? What is the stocking as percent of old plants? What are height and diameter over age? What is height to diameter ratio? Can we see effects of land management, such as grazing? What percent of old plants sprouted?

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[1] Paper presented at Bitterbrush and Cliffrose Symposium in Salt Lake City, Utah, April 13-15, 1982.

[2] Robert E. Martin is Supervisory Research Forester, Pacific Northwest Forest and Range Experiment Station, Bend, Oregon.

[3] Unpublished data, Silviculture Laboratory, Bend, Oregon.

PREVIOUS WORK

Bitterbrush is often considered intolerant of fire, taking many years to reestablish on a site following fire. (An extensive discussion on the factors affecting bitterbrush reestablishment after fire is given in the Martin and Driver paper in this proceedings.)

Hormay (1943) reported that a stand of bitterbrush 2 to 3 ft (61 to 91 cm) tall can become established on a favorable site 15 years after burning. He also reported that cheatgrass (Bromus tectorum) can impede seedling establishment; thus fire is quite damaging to bitterbrush stands. Blaisdell (1950) found the number of bitterbrush plants 15 years after burning varied inversely with the "intensity" of burn, and even light burns still had only about two-thirds the production per acre of the unburned site. He felt that sprouting ability was important in a shrub's rapid recovery after fire.

Multiple stemmed bitterbrush groups grow somewhat faster than single stem plants (Ferguson 1962). Ferguson and Basile (1967) have reported that the increasing seedling numbers in each group (or seed spot) increases the chance of survival.

Nord (1965) and Weaver (1967) state that bitterbrush recovers very slowly following fire. Wright and Bailey (1982) use this to hypothesize that fire occurs only about once every 50 years in the ponderosa pine-bitterbrush type. However, Driver and others (1980) indicate that bitterbrush has mechanisms to recover quickly from fire on the eastern slopes of the Cascade Mountains in Washington through seedlings established on heavily burned areas or by sprouting from a lignotuber just below the groundline.

There seems to be no concurrence on the susceptibility of bitterbrush to fire. Different areas and fire situations seem to yield different responses.

METHODS

I selected 21 prescribed burning units for survey of bitterbrush regeneration. These units were at five locations that ranged from the Deschutes National Forest in central Oregon to Lava Beds National Monument in northeastern California (fig. 1) and were in various ponderosa pine (Pinus ponderosa)-bitterbrush communities. Units had been burned from two to eight growing seasons before sampling in July and August 1980.

An arbitrary point on the boundary of each unit was taken as a starting point. The second-hand of a watch was used to obtain a compass direction for a transect, using the reciprocal direction, if necessary. After moving a suitable distance into the burn unit to avoid edge effect, sample plots were taken at uniform distances along the transect (fig. 2). If we encountered the edge of the unit, we made an offset and took plots along a transect on the reciprocal bearing (fig. 2). Distances between plots varied from unit to unit, depending on unit size.

Plots were 39.37 inches (1 m) radius. Two types of plots were taken--yes/no plots and count plots. On yes/no plots the following data were taken:

1. Bitterbrush seedlings present or not
2. Old bitterbrush plants present or not
3. Old bitterbrush plants sprouting or not

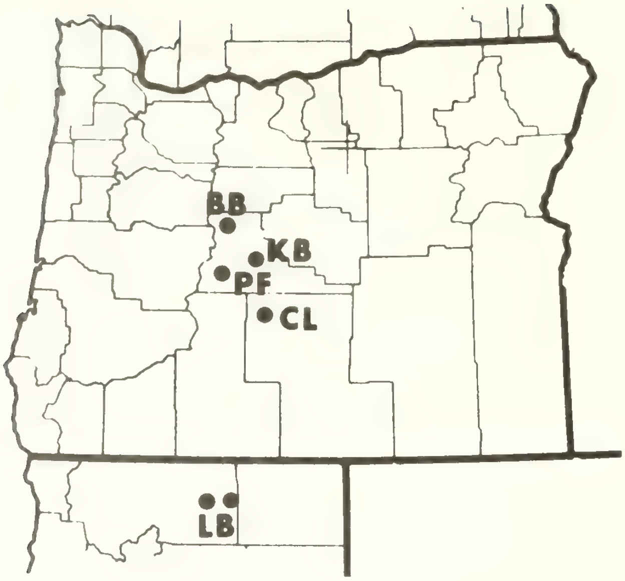

Figure 1.--Locations of burn blocks in central Oregon and northern California.

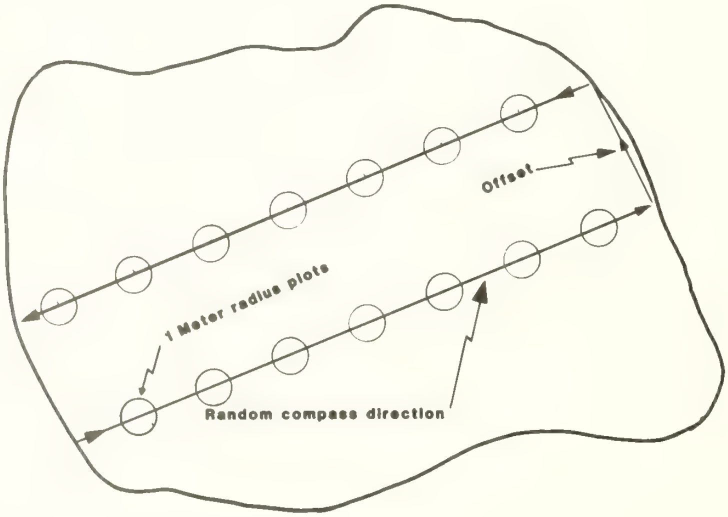

Figure 2.--Schematic of sampling system.

On count plots the following data were taken:

1. Number of bitterbrush seedling groups
2. Number of stems in each group
3. Distance from each seedling group to nearest tree and nearest old tree (>150 years)
4. Age of bitterbrush seedling
5. Height of bitterbrush seedling
6. Diameter of bitterbrush seedling
7. Number of old bitterbrush plants
8. Old bitterbrush plants sprouting or not.

Burning conditions and fuel consumption for each unit were available, but were used in only a general way in analysis. Other general information on units as well as site index and grazing pressure were recorded.

RESULTS AND DISCUSSION

Burn units varied from 0.2 to 50 acres (0.1 to 20 ha), and in site index at 100 years (table 1). The varying unit sizes could affect study results because of the differences in seed availability, rodent populations, grazing and browsing pressure, or microclimate.

Table 1.--Block characteristics of percent stocking, number of seedling groups, and number of stems per group for each location.

Burn location and block	Estimated site index	Date burned	Growing seasons since burn	Months since burn	Number of plots with old bitterbrush	Sprouting	Stocked plots	New bitterbrush plants Number of groups per plot			Stems per seedling group			Plots new Plots old
					Percent	Percent	Percent	$\bar{X}$	S	Range	$\bar{X}$	S	Range	Percent
Black Butte														
1	80	Oct. 1972	8	93	17	0	76	2.19	1.20	0-5	3.13	2.57	1-12	4.47
2	80	May 1973	8	86	87	1	75	5.13	2.77	0-11	2.72	2.39	1-12	.86
3	80	May 1974	7	74	12	0	69	1.78	0.94	0-5	2.90	2.70	1-11	5.42
4	80	Sept. 1975	6	58	88	12	72	4.32	2.51	0-11	2.17	1.72	1-9	.72
Pringle Falls														
Bob's corner	78	May 1976	5	50	79	3	74	2.50	1.54	0-7	1.98	1.63	1-8	.94
1	78	Oct. 1977	4	33	84	2	90	3.63	2.08	0-9	3.74	3.78	1-15	1.05
3	78	Oct. 1977	4	32	39	0	34	3.50	1.97	0-8	4.39	5.90	1-33	.87
4	78	Oct. 1977	4	32	91	2	84	3.12	2.22	0-9	2.17	2.29	1-14	.90
5	78	Oct. 1977	4	32	91	1	74	1.74	1.44	0-6	3.20	3.96	1-21	.80
7	78	Oct. 1977	4	32	97	0	95	5.92	3.91	0-19	2.50	2.71	1-15	.98
Kelsey Butte														
A	75	March 1978	3	29	94	1	87	2.70	2.03	0-8	1.44	1.30	1-9	.92
E	75	May 1978	3	27	79	2	36	1.60	1.15	0-6	1.24	0.66	1-4	.44
Cabin Lake														
1	67	May 1976	5	52	93	0	32	1.50	0.91	0-5	2.10	2.59	1-12	.34
2	67	May 1976	5	52	98	0	36	1.10	0.31	0-2	5.41	4.33	1-14	.37
3	67	May 1976	5	52	89	0	9	1.33	0.71	0-3	2.00	1.76	1-6	.10
4	67	May 1976	5	52	93	0	10	1.30	0.48	0-2	3.08	3.50	1-13	.11
Lava Beds														
1 Upper Ice	78	June 1975	6	62	89	2	58	1.27	0.63	0-3	3.74	4.07	1-16	.64
2 Cave	78	August 1975	6	61	95	2	86	1.48	1.05	0-5	2.58	1.86	1-8	.91
3	78	Oct. 1975	5	59	78	23	40	1.67	0.96	0-4	4.09	3.63	1-15	.51
Caldwell	50	May 1977	4	39	90	10	26	1.07	0.41	0-4	1.07	0.27	1-2	.29
Black Lava Flow	78	June 1979	2	14	82	1	20	1.18	0.73	0-4	6.16	7.99	1-32	.24

Percentage of plots stocked with new bitterbrush plants ranged from 9 to 95 (table 1). Lowest stocking was recorded on the Cabin Lake burns, all of which have experienced heavy cattle grazing. The 5-acre (2.0 ha) burns are located in an area where no other fires have stimulated grass and forage production. Competition from grasses may also be a factor restricting bitterbrush reproduction (Hormay 1943). The Black Lava Flow burn, also low in stocking, had only 14 months between burning and sampling, which may account for its condition. It would probably restock at about the same rate as the three Upper Ice Cave burns, which are close by.

The Caldwell Butte burn at Lava Beds National Monument showed low seedling establishment but high sprouting. The site is quite dry, as indicated by the low site index, and only about 20 percent forested. Open areas with low fuel loading and lower interspecific competition probably account for the relatively high sprouting (Martin and Driver, this proceedings).

Perhaps more indicative of relative success in bitterbrush seedling establishment is the ratio of plots stocked with seedlings compared to those stocked with old plants--a percentage that ranges from 0.10 to 5.42 (table 1). The high percentages obviously come from units with low numbers of old plants and high numbers of seedlings. Any seedlings present before the burn would be missed in the counting, as there would be no postfire evidence of their presence. Generally, these would be relatively few, but would lower the table 1 ratio figures somewhat. Numbers of bitterbrush seedling groups per 33.8 ft^2 (3.14 m^2) plot averaged from 1.07 to 5.92 in each unit, with an individual plot high of 19 (table 1).

Numbers of stems per seedling group also varied considerably, with units averaging from 1.07 to 6.16 and an individual plot high of 33 (table 1). The highest unit average was recorded on the Black Lava Flow burn, the most recent conducted.

Numbers of stems per seedling group tended to decline with the age of the seedling group, although the relationship was generally quite weak. Values of r^2 for regression of number of stems per group against age ranged from 0.1 to 0.73 in linear and polynomial regressions. In all except one of the 21 units, stems per seedling group was negatively correlated with age. This decline could result from both the death of individual stems in a group and the death of entire groups with large numbers of stems because of competition within the group.

Sprouting was generally low among the burn units (table 1). Upper Ice Cave 3 was burned late in the year with high fuel and soil moisture, which may account for the higher sprouting. Fuel consumption was low in the burn and did not cover the entire unit.

Analysis of variance indicates a highly significant difference ($P < 0.01$) among locations for plots containing bitterbrush seedlings (table 2). Calculations were made on all units and also after dropping two units at Lava Beds National Monument. The Black Lava Flow unit was dropped in the second analysis because it was burned only 14 months before counting and the Caldwell unit because it was of low site index and only about 20 percent forested. Further testing for individual differences among locations using the least significant difference technique (Steel and Torrie 1960) showed significant differences ($P < 0.05$).

Location	Percentage of plots stocked	
	21 plots[1]	19 plots[1] [2]
Pringle Falls	75.17^{a}	75.17^{a}
Black Butte	$73.00^{a\ b}$	73.00^{a}
Kelsey Butte	$61.50^{a\ b}$	61.50^{a}
Lava Beds	$46.00^{a\ b\ c}$	61.33^{a}
Cabin Lake	21.75^{c}	21.75^{b}

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[1] Number followed by the same letter indicates no significant difference ($P < 0.05$)

[2] Black Lava Flow and Caldwell units were dropped.

Table 2.--Analysis of variance for plots stocked with bitterbrush seedlings in the five locations.

21 Blocks				
Among locations	4	8610.53	2152.63	4.49[1]
Within locations	16	7184.14	449.01	
Total	20	15794.67		
19 Blocks (without Caldwell and Black Lava Flow)				
Among locations	4	7917.78	1979.44	5.13[1]
Within locations	14	5402.75	385.91	
Total	18	13320.53		

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[1] Significant at 99 percent level of confidence.

Cabin Lake is different from all other locations when two units from Lava Beds are thrown out. This I attribute to cattle grazing and/or grass competition.

The regularity at which seedlings became established on different units also shows the reliability of regeneration following burning. In an attempt to assess this, I plotted cumulative regeneration percent against percent of seasons since burn (fig. 3a-d). Thus, a plot of 45° would indicate the regeneration had come in evenly over the years, as indicated by the diagonal line on each figure. Data from the Black Butte and Kelsey Butte units (fig. 3a) were mostly close to the 45° line, indicating regular annual regeneration over the years. The Pringle Falls units (3b) tended to have annual regeneration but lagged behind the line, perhaps indicating that many of each current year's seedlings are lost. On the other hand, both Cabin Lake and Lava Beds units (3c and d) had wide fluctuations from year to year in the cumulative regeneration. These units seem to have very good and very bad years for regeneration.

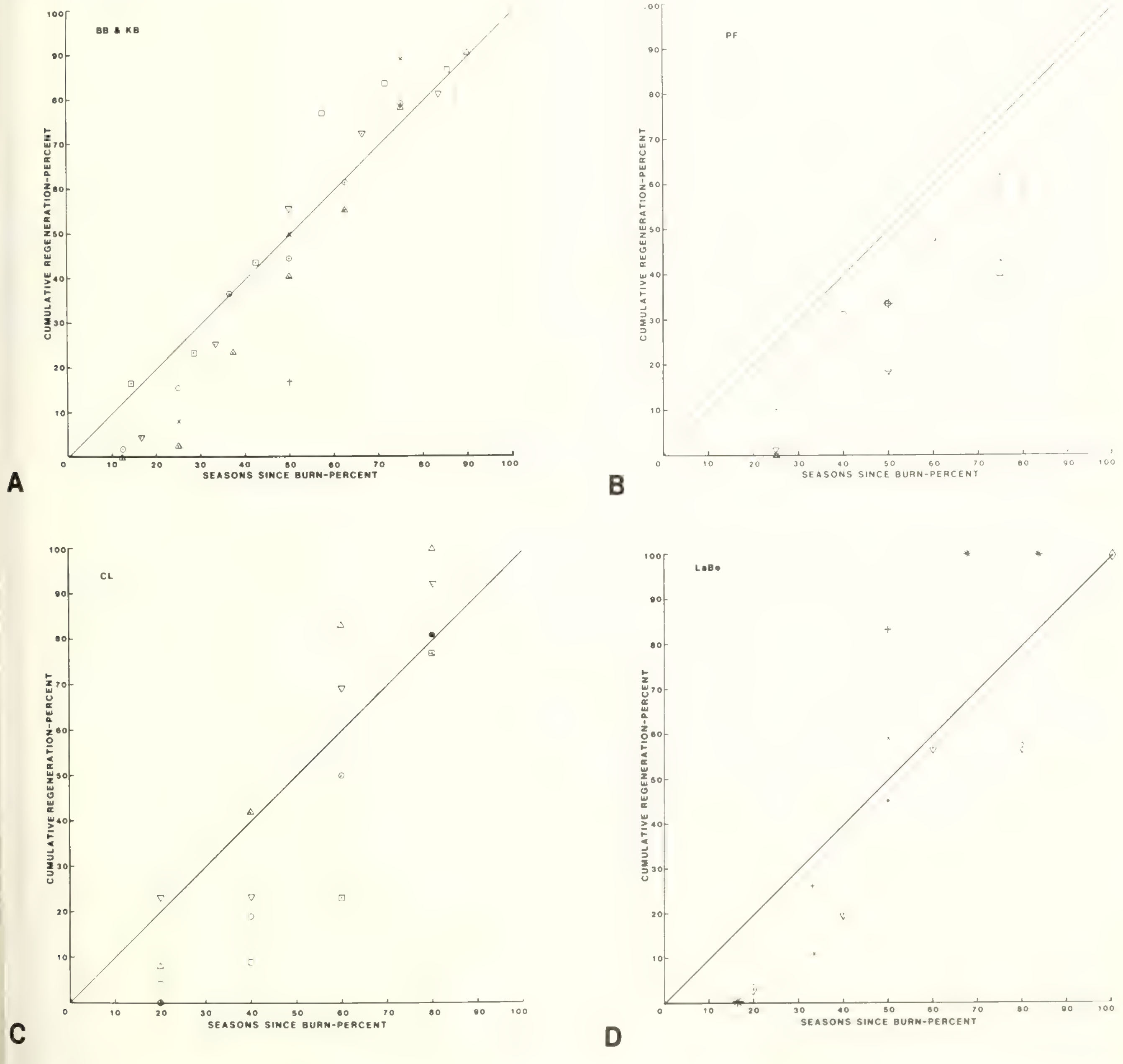

Figure 3.--Cumulative regeneration percent over percent of growing seaons since burn. Black and Kelsey Buttes (a), Pringle Falls (b), Cabin Lake (c), and Lava Beds (d).

To study the rate at which seedlings grow, I used several curve forms to regress height and diameter over age of seedlings (fig. 4 and 5). Curvilinear regression generally accounted for a little more of the variation than did linear regression, but so little was gained that the linear regressions are presented here. The regressions were not tested for significant differences, and there was great variability in the data. Values of r^2 for the regression of height over age varied from only 0.14 for Cabin Lake to 0.74 for Black Butte. In the regressions of diameter over age, r^2 ranged from 0.16 for Cabin Lake to 0.56 for Pringle Falls. All the regressions were highly significant ($P < .01$), and coefficients and F values are given in table 3. Using these figures I would expect bitterbrush plants (groups) to be 5 to 10 inches (12.5 to 25 cm) and 6 to 11 inches (15 to 28 cm) in diameter at 5 years of age, provided they are not extensively browsed. A plot of height/age versus the diameter/age lines indicates the plants (groups) on all units except the Pringle Falls unit to be about three-quarters as high as they are wide (fig. 6).

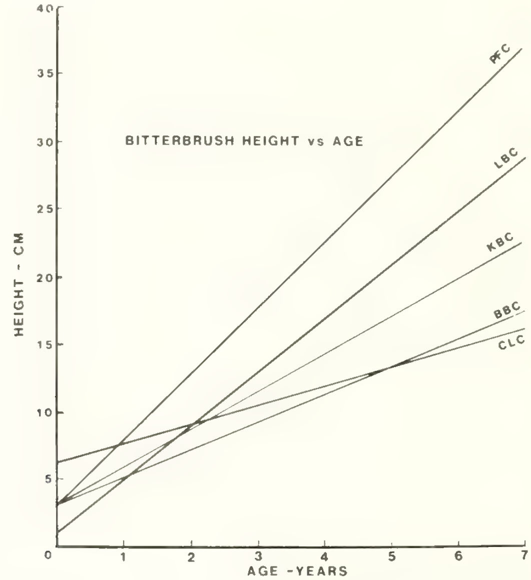

Figure 4.--Height of bitterbrush seedlings regressed over age. Low correlation has reduced the slope of all lines, but especially that of the Cabin Lake (CLC) regression.

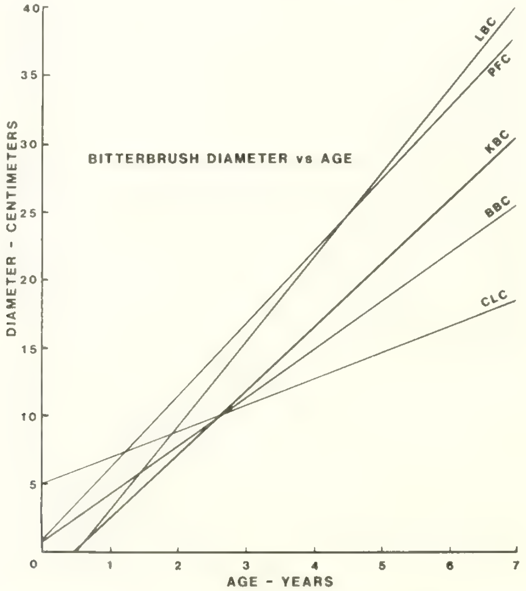

Figure 5.--Diameter of bitterbrush seedlings regressed over age. Cabin Lake had the lowest correlation, greatly reducing the slope of the regression.

Table 3.--Regression values for the highly significant linear regressions among diameter, height, and age of bitterbrush seedlings.

Location	Number observations	Intercept	Coefficient	R^2	F	$S\bar{x}$
Diameter/age						
Black Butte	290	.852	3.51	.55	349.0	5.63
Kelsey Butte	94	-2.28	4.67	.53	102.0	3.59
Pringle Butte	440	.885	5.26	.56	565.0	4.64
Cabin Lake	78	5.41	1.87	.16	14.6	4.82
Lava Beds	142	-3.14	6.16	.48	132.0	7.17
Height/age						
Black Butte	290	3.12	2.04	.55	357.0	3.24
Kelsey Butte	94	3.18	2.78	.36	52.5	2.99
Pringle Butte	440	3.19	4.86	.56	561.0	4.31
Cabin Lake	78	6.16	1.43	.14	11.9	4.08
Lava Beds	142	1.08	4.00	.46	117.0	4.93
Height/diameter						
Black Butte	290	3.64	0.499	.74	823.0	2.47
Kelsey Butte	94	5.38	0.449	.39	59.3	2.92
Pringle Butte	440	3.59	0.762	.68	59.3	3.69
Cabin Lake	78	6.21	0.319	.15	13.0	4.05
Lava Beds	142	4.29	0.557	.69	317.0	3.70

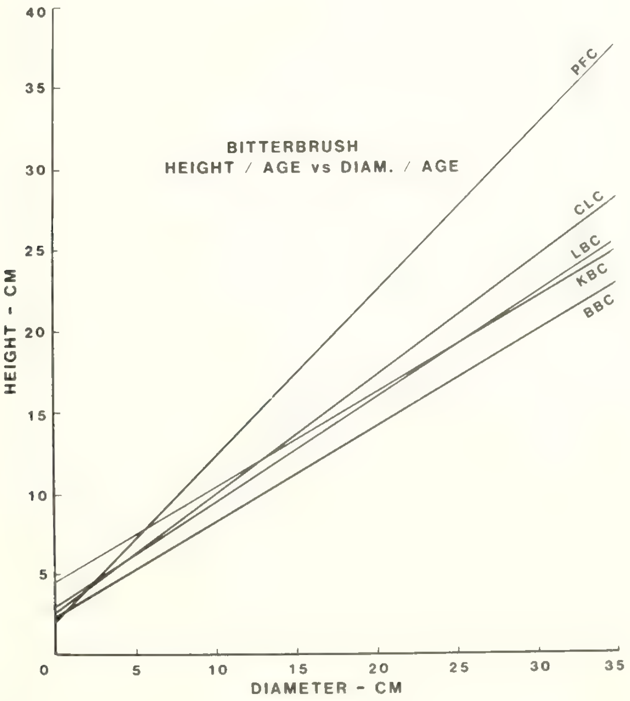

Figure 6.--A plot of height over age versus diameter over age from figures 4 and 5.

SUMMARY

Bitterbrush seedlings have become established rather quickly on prescribed burn units in ponderosa pine/bitterbrush communities in the southern Cascade Mountains of Oregon and California. These extensive communities are important as a game food source. Sprouting of old bitterbrush was generally low, and might be attributed to any of several factors such as plant age, stress from competition, fuel loads, low soil moisture, and burning conditions. The rapid establishment of seedlings would indicate that bitterbrush can regenerate by this means in ponderosa pine stands in pumice regions of the southern Cascade Mountains following fire. Use of fire in these stands could help develop a mosaic of vigorous young bitterbrush in mixture with older plants, perhaps enhancing wildlife habitat.

PUBLICATIONS CITED

Blaisdell, James P. Effects of controlled burning on bitterbrush on the Upper Snake River Plains. Res. Pap. INT-20. Ogden, Utah: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1950. 3 p.

Driver, Charles H.; Winston, Valerie A.; Goehle, Henry F. The fire ecology of bitterbrush--a proposed hypothesis. In: Proceedings of sixth conference on fire and forest meteorology. SAF; Washington, DC: 1980: 204-208.

Ferguson, Robert B. Growth of single bitterbrush plants vs. multiple groups established by direct seeding. Res. Note 90. Ogden, Utah: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1962. 2 p.

Ferguson, Robert B.; Basile, Joseph V. Effect of seedling numbers on bitterbrush survival. J. Range Manage. 20(6): 380-382; 1967.

Hormay, August L. Bitterbrush in California. Res. Note 34. U.S. Department of Agriculture, Forest Service, California Forest and Range Experiment Station; 1943. 13 p.

Martin, Robert E.; Johnson, Arlen H. Fire management of Lava Beds National Monument. In: Proceedings of the 1st conference on scientific research in the National Parks; 1976; New Orleans, Louisiana; Vol. II; 1979: 1209-1218.

Nord, Eamore C. Autecology of bitterbrush in California. Ecol. Monogr. 35(3): 307-334; 1965.

Soeriaatmadja, R. E. Fire history of the ponderosa pine forests of Warm Springs Indian Reservation, Oregon. Corvallis: Oregon State University; 1966. 132 p. Ph.D. thesis.

Steel, Robert G. D.; Torrie, James H. Principles and procedures of statistics. New York: McGraw-Hill; 1960. 481 p.

Weaver, Harold. Ecological changes in the ponderosa pine forest of the Warm Springs Indian Reservation in Oregon. J. For. 57(1): 15-20; 1959.

Weaver, H. Fire and its relationship to ponderosa pine. In: Proceedings tall timbers fire ecology conference; 1967: 7: 127-149.

Wright, Henry A.; Bailey, Arthur W. Fire ecology--United States and southern Canada. New York: John Wiley and Sons; 1982. 501 p.

THE ECOLOGY OF SHRUBS IN BRYCE CANYON NATIONAL PARK WITH SPECIAL REFERENCE TO PURSHIA TRIDENTATA[1]

K. T. Harper and Hayle Buchanan[2]

ABSTRACT

Shrubs contribute more cover than either forbs or graminoides in the forests of Bryce Canyon National Park. Purshia tridentata reaches maximum abundance in the ponderosa pine forests and declines steadily with increasing elevation. Purshia is the major understory species in the low elevation forests. The study covers mortality and establishment rates in six forest types over a 21 year period.

INTRODUCTION

Bryce Canyon National Park is in Garfield and Kane Counties, southcentral Utah. Elevation ranges from 7,915 ft (2,412 m) at park headquarters to 9,105 ft (2,777 m) at Rainbow Point, the highest spot in the park. Geology in the area is dominated by the rather soft Wasatch limestone that has eroded along the edges of the plateau to produce spectacular pink pinnacles and badlands that are the major scenic attractions of the park. Precipitation at headquarters averages about 15.9 inches (40 cm) annually (Eubank and Brough 1979). Precipitation is about equally distributed throughout the year with 25 percent in the January to March period, 22 percent in April to June, 33 percent in July to September, and 20 percent in the October to December interval. Mean annual temperature averaged 41.0°F (5°C) for the 1916-75 interval: January temperatures averaged 21.6°f (-5°C), while July had an average temperature of 62.9°F (17°C) (Eubank and Brough 1979). Deep snowpacks accumulate on the plateau in winter: April 1 water content of snowpacks at headquarters averaged 4.3 inches (11 cm), while water content of snowpacks at Rainbow Point averaged 8.7 inches (22 cm) (Whaley and Lytton 1979).

Although total annual precipitation is unknown for any location other than at headquarters, two general studies relate precipitation to elevation in Utah mountains. Lull and Ellison (1950) showed that annual precipitation in Ephraim Canyon on the Wasatch Plateau (central Utah) increased about 4.9 inches/1,000 ft (12.5 cm/305 m) rise in elevation. Harper and others (1981) reported a 3.0 inches (7.6 cm) increase in precipitation per 1,000 ft (305 m) rise in elevation in the Uinta Mountains of northeastern Utah. Assuming that the relationship between elevation and precipitation at Bryce Canyon National Park is similar to that observed elsewhere in the state, annual precipitation at Rainbow Point probably averages somewhere between 19.5 and 21.8 inches (49.5 and 55.4 cm).

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[1] Paper presented at Bitterbrush and Cliffrose Symposium, Salt Lake City, Utah, April 13-15, 1982.

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OBJECTIVES

The princip~~le~~al objective of this paper is to document the density of *Purshia tridentata* (bitterbrush) in various forest types within Bryce Canyon National Park for the intervals 1957-59 and 1978-80. The data base permits us to describe mortality and establishment rates for that species in six forest types over a 21 year period. We also provide information on associated shrubs, because such data should help managers to put the bitterbrush data into proper ecological perspective.

METHODS

Our report is based on 223 permanently marked study plots sampled in the summers of 1957-59 by Buchanan (1960) and sampled again in 1978-80. At each study plot, a 10.76 ft^2 (1.0 m^2) quadrat was established to sample herbs and shrubs. Trees and tree reproductions at each plot were sampled using the quarter method of Cottam and Curtis (1956). A marking peg at each 10.76 ft^2 quadrat was used as the point from which quarter method distances were measured. All perennial plants in each quadrat were mapped onto gridded paper using a metal frame with 16 equal-sized subsections. About one-third of the study plots were photographed in the initial and again in the later sample.

The sampling points were spaced approximately 300 ft (91 m) apart on a transect that ran along the top of the plateau and nearly the entire length of the park. Direction of the transect was occasionally altered as it encountered park boundaries or edges of the plateau. Compass bearings along each leg of the transect were recorded; distance between plots was measured with a surveyor's chain. The transect began near Rainbow Point and terminated near the park boundary about 1 mile (1.61 km) north of Fairyland View point and some 3 miles (4.83 km) northeast of headquarters. In addition to vegetational characteristics, slope steepness and direction of slope exposure were also recorded at each sampling point. Elevations at sampling points were taken from topographical maps.

After data from the second sample were in hand, individual sampling points were assigned to one of six general forest types based on composition of the tree layer at each point. Finally, several sampling points within each forest type were randomly chosen for analysis for soil depth and other characteristics: those samples were taken in summer of 1981. Soil depth was estimated with a thin (0.39 inch, 1.0 cm) diameter steel rod fitted with a handle at right angles to its length. The sharpened, 3.28 ft (1 m) long rod was pushed into the soil until it struck material that the worker could not penetrate. Five depth samples were taken at each point, one at the center and one in each corner of the 10.76 ft^2 quadrat. Twelve subsamples of the surface 6 inches (1.52 dm) soil (litter layer removed) were taken at each sampling point with a tube sampler. Subsamples were uniformly distributed within the area delimited by the four trees sampled by the quarter method; subsamples were composited for analyses.

RESULTS

We recognized the following forest types at Bryce Canyon: *Pinus ponderosa* - *Juniperus scopulorum* (PIPO-JUSC), *Pinus ponderosa* - *Pseudotsuga menziesii* (PIPO-PSME), *Pinus ponderosa* - *Abies concolor* (PIPO-ABCO), *Pinus flexilis* (PIFL), *Pseudotsuga menziesii* - *Abies concolor* (PSME-ABCO), and *Abies concolor* (ABCO). *Pinus ponderosa* - *Juniperus scopulorum* forest dominated gently rolling, lower elevation sites, while *Abies concolor* was either the dominant or a successionally aggressive species on higher elevation sites. Such sites also tended to be on steeper slopes than those that supported PIPO-JUSC forests (table 1).

Table 1.--General environmental conditions in six forest types at Bryce Canyon National Park. Forest types are identified by major tree dominants. Abbreviations used for trees in this and subsequent tables are as follows: Abies concolor (ABCO, white fir), Juniperus scopulorum (JUSC, Rocky Mt. Juniper), Pinus flexilis (PIFL, limber pine), Pinus ponderosa (PIPO, ponderosa pine), and Pseudotsuga menziesii (PSME, Douglas fir). All values reported are based on the sample sizes reported at the bottom of the table except for soil depth, which was based on sample sizes of 14, 7, 14, 28, 11, and 12 (left to right among forest types). The same letter in superscripts denotes means that do not differ significantly (P .05).

	Forest types					
	PIPO-JUSC	PIPO-PSME	PIFL	PSME-ABCO	ABCO	PIPO-ABCO
Ave. elevation (m)	2,437^{a}	2,519^{b}	2,600^{c}	2,626^{cd}	2,640^{d}	2,651^{de}
Ave. slope (%)	13.6^{a}	24.6^{bc}	26.3^{b}	18.4^{d}	18.0^{d}	17.7^{acd}
Ave. exposure[1]	1.2^{ade}	0.8^{bc}	0.7^{b}	1.0^{ac}	1.5^{d}	0.9^{ce}
Ave. soil depth (cm)	36.5^{a}	25.1^{bc}	34.5^{a}	31.1^{ab}	39.5^{a}	21.6^{c}
Biotic characteristics in 1980 and (1959)						
Trees/ha	178 (84)	163 (101)	312 (221)	676 (300)	682 (436)	262 (138)
Saplings/ha	155 (102)	256 (114)	448 (191)	961 (516)	1,281 (680)	646 (202)
Living cover (understory)						
Forbs (%)	11.6 (11.9)	3.0 (5.0)	3.5 (3.0)	4.8 (5.8)	3.0 (3.0)	7.5 (8.0)
Grasses (%)	4.7 (5.3)	2.0 (4.0)	1.0 (1.0)	2.5 (4.1)	2.0 (3.5)	3.0 (7.0)
Shrubs (%)	11.7 (13.7)	12.0 (17.0)	13.5 (22.0)	8.0 (17.3)	3.0 (5.5)	12.5 (21.0)
Total understory cover (%)	28.0 (30.9)	17.0 (26.0)	18.0 (26.0)	15.3 (27.2)	8.0 (12.0)	23.0 (36.0)
No. plots/type	72	16	29	72	19	15

[1] Exposures are coded according to a scheme suggested by Beers and others (1966): in that scheme, southwesterly slopes receive a value of 0.0, while northeasterly slopes are assigned a value of 2.0. Generally speaking, the larger the value, the cooler the site, all other things being equal.

Purshia tridentata achieved maximum abundance in the PIPO-JUSC forests at the lowest elevations (table 2). *Purshia* tended to become less important as elevation increased; the species was either absent or performed poorly in forests where *Abies concolor* was capable of doing well. Although bitterbrush occurred in 20 percent of the study plots of the PIPO-ABCO forest type that occupies shallow soils at the highest elevations (table 1), the population there suffered 33 percent mortality over the 1959-80 period and was unable to establish any new plants (table 2).

Purshia population densities declined in all forest types over the study period (table 2). Average density loss for the five forest types that had bitterbrush in 1957-59 was 35.9 percent in 20 years. Density losses were low in the PIPO-JUSC forests (21.4 percent) and maximal in the PSME-ABCO community (100.0 percent). Mortality was high in the limber pine forests too, but there, recruitments equalled mortality to give zero change in density (table 2). In general, mortality increased and recruitments declined with elevation.

Table 2.--Density (individuals/10 m^2) of various shrub and subshrub species in the forests of Bryce Canyon National Park in 1980. Additional parameters for *Purshia tridentata* populations are given at the bottom of the table. An asterisk denotes a species that retains the bulk of its foliage during the winter (evergreen).

Species	PIPO-JUSC	PIPO-PSME	PIFL	PSME-ABCO	ABCO	PIPO-ABCO
*Artemisia nova**	1.0	.0	.0	.0	.0	.0
*Arctostaphylos patula**	3.6	8.1	5.5	2.5	.0	2.7
*Berberis repens**	7.5	12.5	12.8	21.2	14.4	13.3
*Ceanothus martini**	.8	2.5	1.7	.6	.0	.7
*Chrysothamnus depressus**	16.7	3.8	5.9	4.2	.0	25.3
*Pachystima myrsinites**	2.2	7.5	7.2	11.8	15.9	28.7
Petradoria pumila	.0	.0	.0	.7	.0	11.3
Purshia tridentata	6.1	1.9	1.4	.0	.0	1.3
Rosa woodsii	.4	.0	3.4	.6	.5	1.3
Symphoricarpos oreophilus	.7	4.4	6.9	7.6	1.1	3.4
*Tetradymia canescens**	.8	.0	.0	.0	.0	.0
Xanthocephalum sarothrae	2.8	.0	.3	.0	.0	4.7
Other *Purshia* parameters						
Frequency (% in m^2 quadrats 1959)	40.3	25.0	17.2	6.9	.0	20.0
Mortality (% from 1959-80)	39.3	50.0	100.0	100.0		33.3
Recruits (No./10 m^2)	1.4	.6	1.4	.0	.0	.0
Density change (% from 1959-80)	-21.4	-25.0	.0	-100.0		-33.3

The princip~~le~~al shrubs associated with *Purshia* in those forest types where it performed best were *Arctostaphylos patula*, *Berberis repens*, *Chrysothamnus depressus*, and *Xanthocephalum sarothrae*. Other species such as *Pachystima myrsinites*, *Rosa woodsii* and *Symphoricarpos oreophilus* occurred infrequently with *Purshia* but achieved best development at higher elevations than that species (table 2).

Although *Purshia* is a winter deciduous species, most of the shrub individuals in these forests are evergreen. Over 70 percent of the shrub or subshrub individuals were evergreen in all six of the forest types (table 2). Of the shrub individuals, 95 percent were evergreen in the most dense (and presumably darkest) forest type (white fir). The success of so many evergreen shrub species in the understory of the Bryce Canyon forests suggests that the characteristic has some adaptive value there. We will return to the question of possible adaptiveness of evergreen leaves.

Over the 21 years of observation, average understory cover declined in all six of the forest types (table 1). The average decline across all forest types was 31.3 percent. Cover of all lifeform groups in the understory declined, but grasses and shrubs declined much more than forbs (table 1). Overall, forbs declined about 9 percent in relative terms, but grasses (39 percent) and shrubs (37 percent) declined over four times faster. Undoubtedly, the declines were strongly influenced by the great increases in forest density and attendant shading: in 21 years, density of trees and saplings roughly doubled on the average in Bryce Canyon forests (table 1). Nevertheless, photographs taken in the initial and the 1978-80 sample demonstrate that many shrub individuals died and left no replacements even in quadrats not overshadowed by trees or saplings.

Although *Cowania*, the other Rosaceous shrub focused in this symposium, did not occur in our samples, we have compared soil physical and chemical parameters in the forest zone of best development of *Purshia* in this study with similar parameters in stands that support *Cowania mexicana* var. *stansburiana* in central Utah (table 3). *Purshia* is shown to occur on deeper, better developed and more fertile soils than *Cowania* (table 3). The smaller rooting volume (soil depth) at *Cowania* sites would be expected to magnify the differences noted for *Cowania* and *Purshia* sites in respect to amounts of essential nutrients per unit weight of soil. Our field experience suggests that these results are probably broadly representative for habitats occupied by these species throughout Utah. *Cowania* is often on rocky outcrops or coarse gravels, while *Purshia* seems to prefer better developed soils. These closely related species thus appear to have diverged along at least edaphic and climatic gradients. Modern distribution patterns suggest that *Purshia* is more tolerant of cold winters and dry summers than *Cowania*.

DISCUSSION

Major changes have occurred in the Bryce Canyon National Park forests during the 21 years of our study. Forests have become more dense and natural succession has altered their composition[3]. Those changes have been associated with less dramatic, but nevertheless large changes in the shrub layers of the forest understories. We have considered response of only *Purshia tridentata* here. The data provide many insights into ecological principles bearing on management of that species.

Our data show that bitterbrush in Bryce Canyon is most competitive at elevations below 8,200 ft (2,500 m). Although it did occur above those elevations at the park, it failed to perform well there: mortality was high -- an average of 71 percent above 8,200 ft as opposed to 39 percent below that elevation; and recruitments were low -- 1.30/100 ft^2 below and 0.46/100 ft^2 above 8,200 ft. Ream's (1963) data for species abundance in 25 northern Utah mountain communities support

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[3] Buchanan, H. and K. T. Harper. Successional dynamics of the forests of Bryce Canyon National Park, Utah. Unpublished manuscript.

Table 3.--Soil characteristics in the ponderosa pine-juniper forest type at Bryce Canyon National Park and in the *Cowania mexicana* var. *stansburiana* community in central Utah (data from Price and Brotherson, in press). Means of each value are followed by their standard deviation. The same letter in superscript denotes means for any given parameter that do not differ significantly (P .05)

	Purshia (PIPO-JUSC type)	*Cowania*
Soil depth (dm)[1]	3.65^{a} ± 1.04	1.79^{b} ± 0.74
Soil texture		
Sand (%)	36.3^{a} ± 7.5	53.6^{b} ± 13.9
Silt (%)	33.1^{a} ± 7.3	27.9^{a} ± 8.5
Clay (%)	30.6^{a} ± 4.2	18.3^{b} ± 7.5
pH	8.2^{a} ± 0.1	7.7^{b} ± 0.4
"Available" phosphorus (ppm)[2]	10.2^{a} ± 14.6	12.8^{a} ± 3.8
Exchangeable		
Calcium (%)	$.91^{a}$ ± 0.23	0.58^{b} ± 0.09
Magnesium (%)	$.08^{a}$ ± 0.02	0.02^{b} ± 0.01
Potassium (ppm)	242.0^{a} ± 161.0	176.0^{a} ± 102.0
Sodium (ppm)	50.0^{a} ± 16.0	97.0^{a} ± 121.0
Sample Size	8	10

[1] Actually soil penetrability with a thin probe. Sample size for this parameter at Bryce Canyon was 14.

[2] On Bryce Canyon soils, phosphorus was extracted with 0.2 N acetic acid, while in the *Cowania* study, the extractant was sodium bicarbonate. The former extractant usually frees more phosphorus than the latter on common soil samples.

our observations at Bryce Canyon. He found *Purshia* in greatest abundance below 6,250 ft (1,900 m) and lacking completely as a significant member of the vegetation above 7,400 ft. Since Ream's (1963) data were taken about 4° farther north, one would expect the species to perform best at lower elevations there than at Bryce Canyon.

Our data suggest that bitterbrush's ability to establish in marginal habitats must be heavily influenced by ephemeral, local conditions. Although the species had once established itself above 7,400 ft at Bryce Canyon, high mortality and poor reproduction suggest that it will not persist in those forest types. Since there is little evidence for significant climatic changes in the Bryce Canyon area during the past half century (McNulty 1947), we conclude that establishment of the species at the higher elevation sites must have been favored by past disruptions of the vegetative cover. Data summarized elsewhere suggest that ground fires and abusive grazing by domestic livestock in the early part of this century probably kept forests at Bryce open and less dark than at present[3].

Others have earlier noted the decline of bitterbrush populations across Utah. As early as 1947, McNulty (1947) described a widespread failure of bitterbrush stands to reproduce in the state. McNulty (1947) blamed the poor reproductive success exclusively on overuse by grazing animals. Our data implicate another cause (community succession) for population declines in bitterbrush populations, even though ungulate grazers may also have been involved.

We tested McNulty's (1947) hypothesis of grazing pressure (domestic and wild ungulates) as the cause for population decline in bitterbrush. Because domestic grazers have been excluded from the park since about 1937 (see footnote 3), we confined our attention to mule deer, the only hooved grazing animal remaining there. The data show (table 4) that deer herd sizes in the area have apparently declined throughout the period 1957-80. Harvest rates from other herd units of Utah for the period 1966-72 were 2.05, 2.63, 3.70, 5.48, and 8.56 animals/km^2 of summer range (North Book Cliffs, Pine Valley Mountains, Elk Ridge, LaSal Mountains, and Blue Mountain herd units respectively)[4]. In comparison, harvest rates for mule deer were 2.79 (unit 50) and 1.85 (unit 60) animals/km^2 of summer range/year from 1961 to 1965, a period of heavy harvests for our study areas. Therefore, deer populations were not unusually large during the period when bitterbrush populations were declining in the park. Declining hunter success through the years also suggests declining deer populations (table 4). Admittedly, such data are difficult to interpret because grazing stress is the result of an interaction between number of grazers and number of available plants per unit area. Nevertheless, it seems likely that grazing pressure alone is not responsible for the observed decline in bitterbrush populations at Bryce Canyon National Park.

Table 4.--Number of mule deer harvested from herd units that surround or lie close to and have habitats similar to those at Bryce Canyon National Park. Unit 50 (Antimony) lies due north of the Park, and unit 60 (Paunsagunt Plateau) includes but has most of its area to the west of the Park. Data are averaged by 5-year intervals for 1951-80 for both units. For a time, unit 60 was subdivided to produce 60B. We combined results for those subunits for the years of their existence. Percent hunter success in the regular season (special hunts ignored) is also reported for the same intervals used for harvest data). Data are from Utah Division of Wildlife Resources (1960-81) reports.

Time interval	Herd unit				Type of hunt
	50		60		
	Harvest	% success	Harvest	% success	
1951-55	998	89.0	282	NA	Either sex
1956-60	1631	70.4	1429	83.4	Either sex
1961-65	1619	67.2	1988	59.7	Either sex
1966-70	613	68.2	743	55.0	Either sex
1971-75	569	46.6	525	39.4	Either sex 1971-73; buck only 1974 on
1976-80	219	31.6	209[1]	24.8	Buck only

[1] area partially closed in 1980.

NA = data not available.

Mooney and Gulmon's (1982) considerations relative to leaf duration have relevance to this study in two ways. Their work suggests that the prevalence of evergreen-leaved shrubs at Bryce Canyon may be related to the uniform distribution of precipitation throughout the year and/or to low availability of phosphorus, a critical element for plant growth (table 3). Also, full consideration of the comparative ecology of *Purshia tridentata* and *Cowania mexicana* var. *stansburiana* must include evaluation of the consequences of their difference in leaf duration. If Mooney and Gulmon's (1982) conclusions are broadly applicable, one would predict that bitterbrush (deciduous) should have higher photosynthetic rates and faster growth than its evergreen-leaved relative, *Cowania*. Their generalizations also suggest that the leaves of the former species should have higher protein levels and be more palatable to herbivores. Leaf duration may explain why bitterbrush has extended its range far into the summer-dry Great Basin and Pacific Northwest, while *Cowania*'s range and abundance patterns are well correlated with the summer rain zone of the Southwest. Those observations conform to expectations suggested by the Mooney-Gulmon hypothesis relative to leaf duration: one would expect the evergreen species to perform best where the moisture supply was more uniform. The different edaphic preferences of these two shrubs also fit expectations for deciduous and evergreen taxa, with the evergreen species occurring where nutrients are more limiting.

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[4] Pederson, J. C. and K. T. Harper. Does summer range quality influence sex ratios among mule deer fawns in Utah? (In press).

PUBLICATIONS CITED

Beers, T. W.; Dress, P. E.,; Wensel, L. C. Aspect transformation in site productivity research. J. For. 64: 691-692; 1966.

Buchanan, H. The plant ecology of Bryce Canyon National Park. Salt Lake City: University of Utah; 1960. 136 p. Dissertation.

Cottam, G.; Curtis, J. T. The use of distance measures in phytosociological sampling. Ecology. 37: 451-460; 1956.

Eubank, M. E.; Brough, R. C. Mark Eubank's Utah weather. Bountiful, UT: Horizon Publishers; 1979. 284 p.

Harper, K. T.; Woodward, R. A.; McKnight, K.B. Interrelationships among precipitation, vegetation and streamflow in the Uinta Mountains, Utah. Encyclia. 57: 58-86; 1981.

Lull, H. L.; Ellison, L. Precipitation in relation to altitude in central Utah. Ecology. 31: 479-484; 1950.

McNulty, I. B. The ecology of bitterbrush in Utah. Salt Lake City: Univeristy of Utah; 1947. 38 p. Master's thesis.

Mooney, H. A.; Gulmon, S. L. Constraints on leaf structure and function in reference to herbivory. Bioscience. 32: 198-201, 204-206; 1982.

Ream, R. The vegetation of the Wasatch Mountains, Utah and Idaho. Madison, WI: University of Wisconsin; 1963. 178 p. Dissertation.

Utah Division of Wildlife Resources. Big game investigations and management recommendations. Salt Lake City: Utah Division of Wildlife Resources; 1960-81. Published annually.

Whaley, B. L.; Lytton, L. K. Summary of snow survey measurements for Utah. Salt Lake City: U.S. Department of Agriculture, Soil Conservation Service; 1979. 321 321 p.

RESPONSE OF THE BITTERBRUSH UNDERSTORY OF A CENTRAL OREGON LODGEPOLE PINE FOREST TO LOGGING DISTURBANCE[1]

Paul J. Edgerton[2]

ABSTRACT

Logging and slash disposal caused extensive soil disturbance and physical damage to the bitterbrush understory. After 5 years, substantial recovery had occurred due to increased twig growth of surviving shrubs and establishment of shrub seedlings on disturbed soils. Apparent increases in herbaceous species added needed diversity to the forage resource.

INTRODUCTION

Lodgepole pine (Pinus contorta Dougl. ex Loud)[3] forests of the pumice soil region of central Oregon are important summer range for mule deer (Odocoileus hemionus hemionus) and livestock. Antelope bitterbrush (Purshia tridentata [Pursh] DC.) dominates the understory over much of the area and is the major forage species (Stuth 1975). Advances in wood processing technology have resulted in the acceleration of timber harvest in these forests. Because the pumice soils are easily disturbed, land managers need a better understanding of the impact of logging on the understory in order to develop appropriate management strategies that will maintain or enhance the forage resource.

Bitterbrush response to logging disturbance has been studied on a timber sale on the Pringle Falls Experimental Forest in Oregon. Purpose of the study was (1) to determine the extent of soil disturbance and reduction of the shrub understory, and (2) to document subsequent understory recovery due to growth response of surviving shrubs and the establishment of new shrubs and herbaceous plants. An earlier paper (Edgerton and others 1975) reported initial disturbance and understory response. To further document understory recovery, this paper compares those data taken 2 years after disturbance with data collected at 5 years.

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[1] Paper presented at the Bitterbrush and Cliffrose Symposium, Salt Lake City, UT, April 13-15, 1982.

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[3] Sources for scientific nomenclature are Little (1953), Hitchcock and others (1955-1969), and Ingles (1965).

STUDY AREA

The study was conducted approximately 40 mi (64 km) southwest of Bend, Oregon. Elevation is 4,300 ft (1 310 m). Precipitation averages 20 inches (50.8 cm) annually, occurring mostly as winter snowfall. Frosts are common during the short growing season.

Soils and vegetation are characteristic of much of the level to gently rolling plateau. Soils are Typic Cryorthents, belonging to the Lapine series formed on pumice ejected from Mt. Mazama about 6,500 years ago. They are primarily composed of easily disturbed sand and pumice gravels, variable in depth, and underlain by buried soil (Cochran and others 1967). Lodgepole pine occurs in extensive, nearly pure stands on flats and in shallow depressions where it is the topographic climax species (Berntsen 1967). Youngberg and Dahms (1970) identified several forest types dominated by lodgepole pine with lodgepole pine/bitterbrush the most extensive. According to Volland's (1976) more detailed classification of plant communities of the pumice zone, the study area is best described as lodgepole pine/bitterbrush/forb. Other common understory plants include western needlegrass (Stipa occidentalis Thurb. ex Wats.), bottlebrush squirreltail (Sitanion hystrix [Nutt.] J. G. Sm.), Ross sedge (Carex rossii Boott), and least lupine (Lupinus lepidus Dougl.).

The study was conducted in three adjacent cutting units, 396 ft by 2,640 ft (121 m by 805 m) in size, separated by unlogged forest. The units are level and prior to logging supported a lodgepole pine forest relatively uniform in size and density. A diameter-limit harvest of trees 9 inches (23 cm) diameter at breast height (dbh) and larger reduced stems by 67 percent and basal area 78 percent. Logged stands averaged 114 trees per acre (282 per ha) with 20.5 ft^2 (4.7 m^2) basal area. Adjoining unlogged stands averaged 339 trees per acre (837 per ha) with a basal area of 91.3 ft^2 (21.0 m^2).

Logging and slash disposal occurred between 1969 and 1971. Most logs were yarded by rubber-tired skidders, but a D-4 crawler tractor was also used. Slash was piled by TD-6 and D-8 tractors with brush blades and burned on two units in 1970 and on the remaining one in 1971.

METHODS

Prior to logging, nine randomly located 100-ft (30.5-m) line transects were established in each unit and marked inconspicuously to minimize their influence on the operation of logging equipment. Ground disturbance caused by logging and slash disposal was estimated in November 1972 using the line interception method (Canfield 1941). Changes in bitterbrush crown area were measured by the line intercept method in November 1967, before logging, and in 1972 and 1975, 2 and 5 years after logging and slash disposal.

Comparative growth response of surviving shrubs was determined from linear measurements of current twig growth on randomly chosen secondary branches on 30 mature shrubs in each logged and adjoining unlogged stand. Measurements were taken at the end of the growing season and did not include lateral spur growth less than 0.4 inch (1 cm) in length.

Changes in bitterbrush density and age structure were determined from counts of shrubs on 27 circular plots, each 100 ft^2 (9.3 m^2). The plots were systematically located in each logged unit and adjoining unlogged stand. Groups of young plants that likely had emerged from rodent caches were counted as single plants and care was taken to minimize errors due to layered and multiple stems commonly found in mature bitterbrush. Two years after logging, shrubs were classified as seedlings 1 to 3 years old, and $\geq$ 3 years. At 5 years, they were classified as current seedlings or established plants.

The data were studied using analyses of variance comparing (1) crown area before logging versus 2 and 5 years after logging, (2) twig growth in logged versus unlogged stands, and (3) shrub densities and age in logged versus unlogged stands at 2 and 5 years.

Lodgepole pine regeneration was surveyed on 27 circular plots, each 436 ft^2 (40.5 m^2). These plots were systematically located in each logged unit. Additional data were taken to describe the development of associated understory vegetation. Percent canopy coverage of herbaceous species and other shrubs was estimated according to the technique described by Daubenmire (1959). Three transects of 30 plots, each 12 by 23 inches (30.5 by 58.4 cm), were randomly located perpendicular to the long axis of each logged unit and adjoining unlogged stand.

RESULTS AND DISCUSSION

The initial impact of logging and slash disposal on the soil and understory vegetation was severe and extensive: 90 percent of the ground surface was disturbed, of which 78 percent was classified as moderate (< 3 inches or 7.6 cm deep) or heavy (> 3 inches or 7.6 cm deep) disturbance (table 1). Average bitterbrush crown area (table 2) was reduced from 15.1 percent before logging to 4.3 percent 2 years after logging, a relative change of 72 percent.

Slash piling with a blade apparently caused more soil disturbance and shrub damage than did log skidding. Although skidding partially damaged shrubs, many survived. Slash piling, however, churned soils as deep as 12 inches (30 cm) in the piles and on fire lanes circling them, causing most shrubs to be broken, uprooted, or buried.

Fortunately postlogging recovery of the shrub understory has been equally dramatic. Logging created a favorable environment for more vigorous growth of surviving shrubs as well as the germination and establishment of new shrubs. Intercept measurements showed that crown area increased significantly ($P < 0.05$) from 2 to 5 years after disturbance to equal prelogging values.

Increased twig growth made an important contribution to recovery. Current annual twig growth of surviving shrubs in logged units significantly ($P < 0.05$) exceeded that of unlogged units both 2 and 5 years after logging (table 3). Surviving shrubs in the logged areas also appeared to be more vigorous and produced more twigs. In a similar plant community, Stuth and Winward (1976) reported that terminal and lateral leaders accounted for 71 percent of shrub production in logged areas, while short spurs produced more than one-half of the current production in adjoining unlogged stands. The fact that mule deer and livestock prefer leaders and seldom utilize spur growth (Stuth 1975) underscores the potential forage contribution of logged areas.

Table 1.--Ground disturbance due to logging and slash disposal

Disturbance class	Description	Percent of area in this condition
None	No disturbance	8
Light	Litter displacement only	12
Moderate	Soil disturbed < 7.6 cm	32
Heavy	Soil disturbed > 7.6 cm	46
Slash	Debris > 7.6 cm diameter	2
All classes		100

Table 2.--Changes in bitterbrush crown area following logging disturbance

Logging unit number	Prelogging	Crown area	
		2 years	5 years
	Percent		
1	14.9	3.7	21.7
2	14.8	3.8	20.4
3	15.5	5.4	18.2
Average	15.1	4.3	20.1

Table 3.--Current annual growth of bitterbrush twigs in logged versus unlogged lodgepole pine stands 2 and 5 years after logging

Logging unit number	Twig length			
	Logged		Unlogged	
	2 years	5 years	2 years	5 years
	mm			
1	69.2	80.0	35.6	46.1
2	68.4	70.9	38.8	43.0
3	81.1	73.4	30.8	41.7
Average	72.9	74.8	35.1	43.6

Rapid establishment of new shrubs, primarily on moderately and heavily disturbed soils, is reflected in shrub population densities shown in table 4. Just 2 years and subsequently 5 years after loss of 72 percent of the understory, shrub densities of logged and unlogged stands were not significantly different ($P > 0.05$), but there were significant differences ($P < 0.01$) in age structure. Logging converted an older mature stand to one dominated by younger plants. These understory changes are apparent in the photo comparison in figure 1. Shrubs established since logging accounted for nearly 70 percent of bitterbrush in logged stands but less than 10 percent in unlogged stands.

Table 4.--Bitterbrush density per hectare in logged and unlogged lodgepole pine stands

Age class	Unlogged	Logged Years after logging 2 years	 5 years
Current seedlings	1,274	1,593	2,868
Established since logging	2,048	13,827	19,577
Established before logging	20,421	5,641	5,641
All shrubs	23,743	21,061	28,086

Shrub densities exceeding 8,000 per acre (19,760 per ha) found in this study may seem unusually high. On most shrub-steppe ranges, 500 to 2,000 shrubs per acre (1,235 to 4,940 per ha) are considered adequate stocking (Hubbard 1962). Shrubs in these forest communities, however, are small in stature and many of those beneath the lodgepole canopy appear suppressed and low in vigor. Stanton (1959) reported comparable densities in similar lodgepole communities near La Pine, Oregon.

Successful recovery of the shrub understory in these forests depends on the number, size, and condition of surviving shrubs as well as the extent of soil disturbance and environmental conditions created by logging. Stuth and Winward (1976) noted that shrubs 8 to 16 inches (20 to 40 cm) in height had a higher survival rate and better growth response than did smaller plants. Shrubs taller than 16 inches (40 cm) were more easily damaged and didn't respond well to environmental changes. A good distribution of large plants, however, was suggested to maintain seed production for regeneration. Size of surviving shrubs was not measured in this study, but a wide range of size classes was observed. Ample regeneration is evidence of adequate seed production.

Environments of the logged units during the initial two seasons following disturbance apparently were conducive not only to seed production but also to subsequent germination of rodent caches and seedling establishment. The partial tree canopy remaining probably ameliorated harmful minimum growing season temperatures that commonly occur in clearcuts in the pumice region (Cochran and others 1967). Stuth and Winward (1976) found a significant correlation between density of successful caches and cover and/or density of the tree overstory. Cochran (1969) reported similar benefits of the tree canopy to lodgepole pine regeneration.

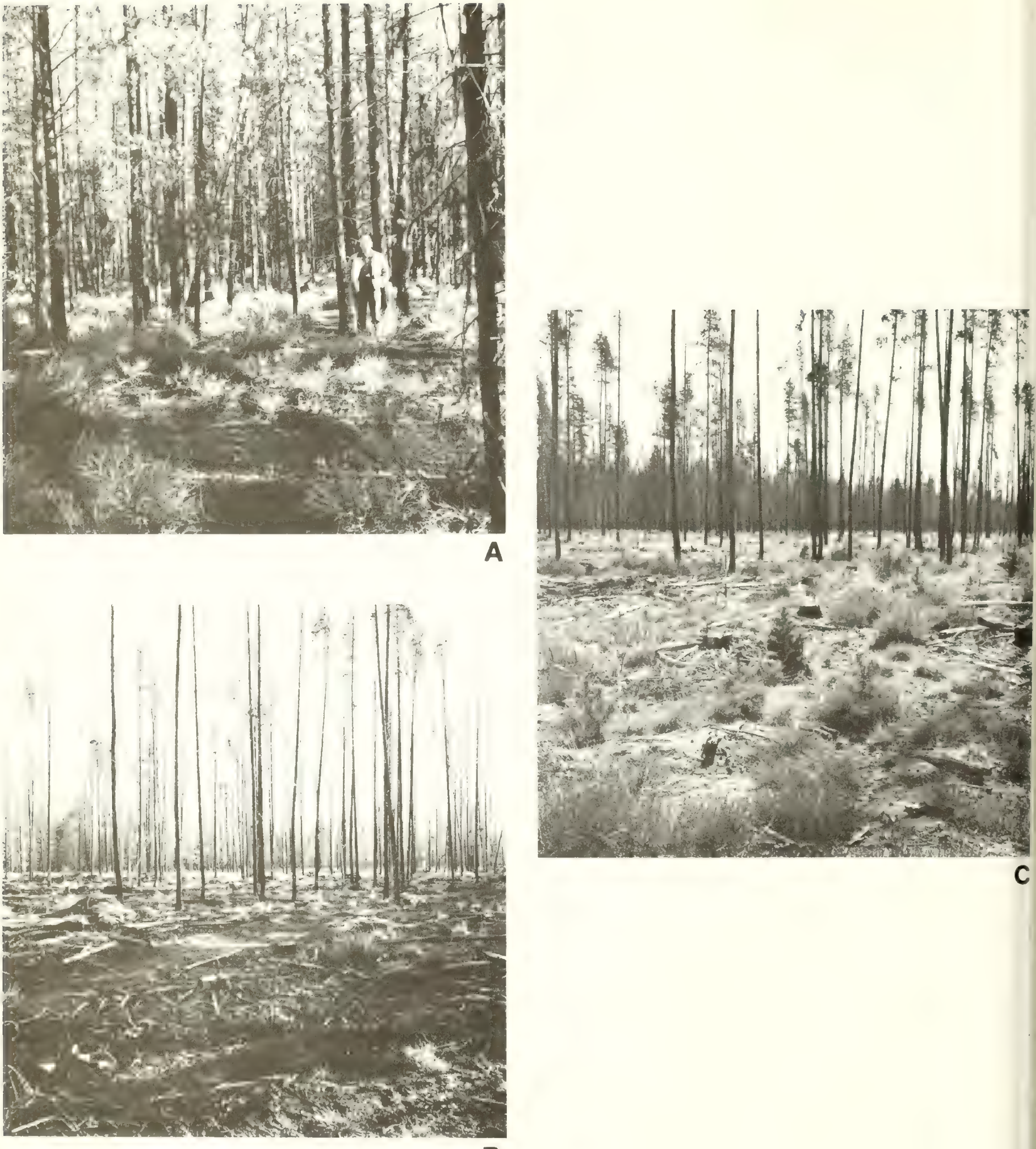

Figure 1.--Unlogged and logged lodgepole pine-bitterbrush forest: (A) Unlogged stands with mostly mature bitterbrush shrubs. (B) Logged stands 2 years after logging; 73 percent of bitterbrush were seedlings and small shrubs established since logging. (C) The stands 5 years after logging; 80 percent of bitterbrush were seedlings and young established shrubs. Lodgepole pine established since logging averaged 597 tre per acre (1,475 per ha).

Apparent increases in the quantity and diversity of native herbaceous vegetation also contributed to forage recovery. Five years after disturbance, average canopy cover of grasses and sedges was 1.9 percent and 5.7 percent in unlogged and logged stands, respectively. Ross sedge and bottlebrush squirreltail made the largest gains. Several forbs also were more abundant, with average cover increasing from 0.6 to 1.5 percent.

Reforestation is another important consideration in evaluating logging impacts in these forest communities. Rodents, insects, ungulate browsing, harsh microclimates, and soil factors often hinder seed production, germination, seedling establishment, and early growth. Fortunately, 5 years after disturbance, these logged units averaged 597 newly established trees per acre (1,475 per ha) as compared to 339 mature trees per acre (837 per ha) in adjoining unlogged stands. Successful regeneration is the primary goal of foresters, but wildlife managers realize that as logging progresses into adjacent stands, maintenance of deer habitat will depend on the development of suitable resting and escape cover in previously harvested stands.

CONCLUSIONS

Study results show that silvicultural treatments can enhance bitterbrush and other forage species in central Oregon lodgepole pine forests. Acceptable levels of soil and understory disturbance can be achieved by selection of appropriate harvest methods and equipment. Special attention should be given to developing silvicultural prescriptions that ameliorate harsh environmental extremes often limiting establishment of shrub and tree seedlings.

Where excessive tree regeneration is thinned, these and similarly harvested stands should serve as important forage areas for mule deer and livestock for, perhaps, 15 years or more. Consideration for other habitat requirements such as cover must be planned in adjacent stands to realize full benefit of this resource. To this end, foresters, biologists, and range managers must work together to assure a balance of habitats of appropriate size, arrangement, and stand condition.

PUBLICATIONS CITED

Berntsen, C. M. Relative low temperature tolerance of lodgepole and ponderosa pine seedlings. Corvallis, OR: Oregon State University; 1967. 158 p. Ph. D. dissertation.

Canfield, R. Application of the line interception method in sampling range vegetation. J. For. 39: 388-394; 1941.

Cochran, P. H. Lodgepole pine clearcut size affects minimum temperatures near the soil surface. Res. Pap. PNW-86. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1969. 9 p.

Cochran, P. H.; Boersma, L.; Youngberg, C. T. Thermal properties of a pumice soil. Soil Sci. Soc. Proc. 31: 454-459; 1967.

Daubenmire, R. A canopy-coverage method of vegetational analysis. Northwest Sci. 33: 43-64; 1959.

Edgerton, P. J.; McConnell, B. R.; Smith, J. G. Initial response of bitterbrush to disturbance by logging and slash disposal in a lodgepole pine forest. J. Range Manage. 28: 112-114; 1975.

Hitchcock, C. L.; Cronquist, A.; Ownbey, M.; Thompson, J. W. Vascular plants of the Pacific Northwest. Seattle, WA: University of Washington Press; 1959-69. 5 vol.

Hubbard, R. L. The place of browse seeding in game range management. In: Twenty-seventh North American Wildlife and Natural Resources Conference Transactions; 1962: 394-401.

Ingles, L. G. Mammals of the Pacific states: California, Oregon and Washington. Stanford, CA: Stanford University Press; 1965. 506 p.

Little, E. L., Jr. Checklist of native and naturalized trees of the United States (including Alaska). Agric. Handb. 41. Washington, DC: U.S. Department of Agriculture; 1953. 472 p.

Stanton, F. W. Autecological studies of bitterbrush (*Purshia tridentata* (Pursh) DC.). Corvallis, OR: Oregon State University; 1959. 188 p. Ph. D. dissertation.

Stuth, J. W. Livestock, deer and logging interactions in the lodgepole pine-pumice region of central Oregon. Corvallis, OR: Oregon State University; 1975. 175 p. Ph. D. dissertation.

Stuth, J. W.; Winward, A. H. Logging impacts on bitterbrush in the lodgepole pine-pumice region of central Oregon. J. Range Manage. 29: 453-456; 1976.

Volland, L. A. Plant communities of the central Oregon pumice zone. R6 Area Guide 4-Z. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Region; 1976. 110 p.

Youngberg, C. T.; Dahms, W. G. Productivity indices for lodgepole pine on pumice soils. J. For. 68: 90-94; 1970.

LONG-TERM CHANGES IN AN UNGRAZED BITTERBRUSH PLANT COMMUNITY IN SOUTHWEST IDAHO[1]

Robert B. Ferguson and Dean E. Medin[2]

ABSTRACT

Successional changes and the effects of winter browsing by deer were evaluated by periodically sampling the vegetation of an Idaho winter range site dominated by bitterbrush. Over 23 years of study, bitterbrush density decreased while canopy cover increased. Rabbitbrush density increased, but canopy cover remained relatively stable. Effects of slope exposure on vegetation changes were small. Variety of herbaceous perennials increased, whereas variety of annuals was static. Deer use was not a significant factor in vegetation change. Browse production probably decreased because of increasing age of bitterbrush shrubs. In light of slow vegetational change on bitterbrush-dominated winter range, land managers should consider rejuvenation of old stands by topping, or increasing stand density through revegetation.

INTRODUCTION

During the 1950's some land managers believed that bitterbrush (Purshia tridentata Pursh D.C.) stands in southern Idaho were deteriorating. As early as 1929, this same opinion was expressed regarding severely overgrazed ranges in Utah (Forsling and Storm 1929). In Idaho, bitterbrush was considered the most valuable forage shrub on many winter ranges used by mule deer (Odocoileus hemionus), and much speculation existed concerning the long-term trend of plant composition where bitterbrush was an important component. Winter ranges along the Middle Fork of the Salmon River and the South Fork of the Payette River sustained only a fraction of the number of bitterbrush plants that had flourished there during the 1930's and early 1940's (Holmgren and

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Basile 1956; Shaw and Nielson 1951). The decline of bitterbrush on the Payette River range was in part accelerated by fire that increased the density of cheatgrass (Bromus tectorum L.), which in turn provided severe competition for bitterbrush seedlings. Cicadas also damaged the bitterbrush on the Payette winter range in 1943. These factors, plus the large deer population at the time, resulted in a large decrease in bitterbrush stand density and productivity.

To gain further insight into plant succession, and to compare the changes in vegetation resulting from protection from deer browsing with those occurring on adjacent, unprotected areas, the study reported here was begun in 1955.

METHODS

In December 1953, the Idaho Fish and Game Department erected a 1-acre (0.4-ha) deer-and-cattle-proof enclosure on winter range north of the Boise River, in Boise County, Idaho. The exclosure is located about 0.5 mile (0.8 km) east of the mouth of Mores Creek at an elevation of 3,200 ft (976 m). The immediate area is within a major deer migration route and has historically sustained heavy concentrations of deer in most winters. Livestock grazing, although probably heavy in past years, has been limited to only occasional trailing of cattle since the early 1950's. About 60 percent of the area within the exclosure faces primarily southwest and the remainder faces east.

In the spring of 1955, twelve 50-ft (15.24-m) line transects were established within the enclosure: 6 on the southwest slope and 6 on the east slope. Twelve comparable line transects were established on the same slopes just outside the exclosure. Figure 1 shows a portion of the southwest slope, both inside and outside the exclosure, on which some of the transects were located. Each line transect also served as the downslope edge of a 4-ft by 50-ft (1.22-m by 15.24-m) belt transect and a 6-inch by 50-ft (15.24-cm by 15.24-m) belt transect.

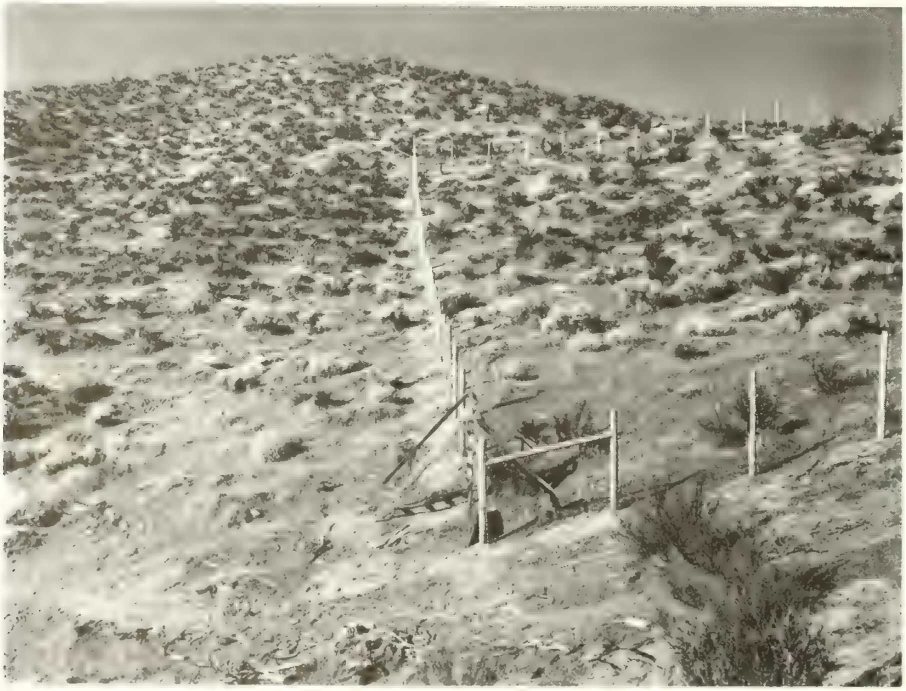

Figure 1.--Portion of the southwest-facing slope of the study area, photographed in February 1954, a year before the study was started.

Data were recorded from the 24 transects in early June 1955, 1958, 1963, 1968, 1973, and 1978. The line transects were used to obtain data on canopy intercept of shrub species and basal intercept of all perennial plant species (Canfield 1942). Canopy intercept was measured to the nearest 0.1 ft (3 cm). The 4-ft by 50-ft belt transect was used to obtain density of all perennial plant species. Data on percent frequency and percent composition of perennials were obtained by dividing this transect into five 10-foot (3.05-m) segments, and recording data on perennials by transect segments. Data on percent frequency and density of annual species were similarly obtained by dividing the 6-inch by 50-foot belt transects into 50 segments of 1 ft each. Constancy of annual species was determined as the percent of 50-ft transects on which each species was encountered.

RESULTS

Shrub Cover and Density

Bitterbrush canopy cover increased slightly more rapidly on the areas exposed to deer browsing than on the areas protected by the exclosure. Over the 23-year study, the mean canopy cover increased from 24.2 to 32.2 percent (a 30 percent increase) inside the exclosure compared to an increase from 16.7 to 23.0 percent (a 38 percent increase) outside the exclosure (table 1).

Table 1.--Mean percent canopy cover of bitterbrush and rabbitbrush, on browsed and protected areas and by aspect of slope, for each year of sampling

	Year					
	1955	1958	1963	1968	1973	1978
itterbrush						
rowsed, SW	10.6	14.7	13.6	15.5	15.9	16.3
rowsed, E	22.8	21.6	20.5	21.5	26.2	29.6
Mean	16.7	18.2	17.0	18.5	21.0	23.0
rotected, SW	20.5	18.8	22.8	21.8	28.4	29.8
rotected, E	27.8	28.7	33.7	32.1	32.6	34.6
Mean	24.2	23.8	28.2	27.0	30.5	32.2
ubber rabbitbrush						
rowsed, SW	3.4	3.3	4.8	3.1	3.6	4.7
rowsed, E	7.8	6.6	7.0	7.6	6.9	5.6
Mean	5.6	5.0	5.9	5.4	5.2	5.2
rotected, SW	3.4	2.7	4.3	3.9	5.7	5.8
rotected, E	1.1	2.5	1.9	2.1	2.9	3.6
Mean	2.2	2.6	3.1	3.0	4.3	4.2
otal cover						
rowsed	22.1	23.1	23.0	23.6	25.4	29.0
rotected	26.4	26.1	31.2	30.0	34.8	36.4
outhwest slope	19.0	19.8	22.6	22.2	26.8	27.8
ast slope	29.6	29.6	31.6	31.6	34.3	37.6

Rubber rabbitbrush (Chrysothamnus nauseosus [Pallas] Britt.) was the only other shrub encountered on the transects, except for a couple of golden currant (Ribes aureu Pursh) shrubs on the east slope, outside the exclosure.

From 1955 to 1978, mean canopy cover of rabbitbrush inside the exclosure increase from 2.2 to 4.2 percent, while mean canopy cover outside the exclosure decreased from 5.6 to 5.2 percent. Thus, rabbitbrush remained a relatively stable component of the shrub stand throughout the 23 years of observations.

The effects of slope exposure on the bitterbrush-rabbitbrush stand were small. the southwest-facing slope, both inside and outside the exclosure, both species increased in canopy cover while the percent composition remained essentially the same. On the east-facing slope, both species increased in canopy cover inside the exclosure, but rabbitbrush decreased while bitterbrush increased on transects outside the exclosure.

With respect to shrub density, the number of bitterbrush plants on protected transects decreased from 41 to 33 (a 20 percent decrease); 10 of the original plants died, but 2 new ones became established. On unprotected transects the number of bitterbrush plants decreased from 37 to 34 (an 8 percent decrease); 6 of the original plants died, but 3 new ones became established. Overall, bitterbrush density decreased from 726 to 626 per acre (294 to 253 per ha). The mean height of bitterbru shrubs increased approximately the same amount on all transects--about 9 inches (23 c over the 23 years.

The number of rabbitbrush plants increased from 8 to 27 (a 237 percent increase) on transects inside the exclosure; 2 of the original 8 plants died, but 21 new plants became established. On transects outside the exclosure, the rabbitbrush plants increased from 16 to 58 (a 262 percent increase); 10 of the original 16 plants died, but 52 new plants became established.

Cover and Density of Herbaceous Perennials

Total basal intercept of perennial grasses and forbs decreased slightly, both inside and outside the exclosure, over the 23 years (fig. 2). However, the observed changes varied according to slope exposure. On the southwest slope basal intercept remained virtually constant (and very low) inside the exclosure, but increased slight outside the exclosure over the last decade of the study period. Basal intercept of herbaceous perennials decreased by nearly an identical amount on east slopes inside outside the exclosure.

While total basal intercept apparently declined, except on the unprotected southwest slope, total density of herbaceous perennials (including biennials, but excluding Sandberg bluegrass [Poa secunda Presl.], and needle-leaved phlox [Phlox aculeata Nels.]), steadily increased over the 23 years (table 2). Density of perennials appears to have increased more rapidly outside the exclosure than inside, but was unaffected by slope.

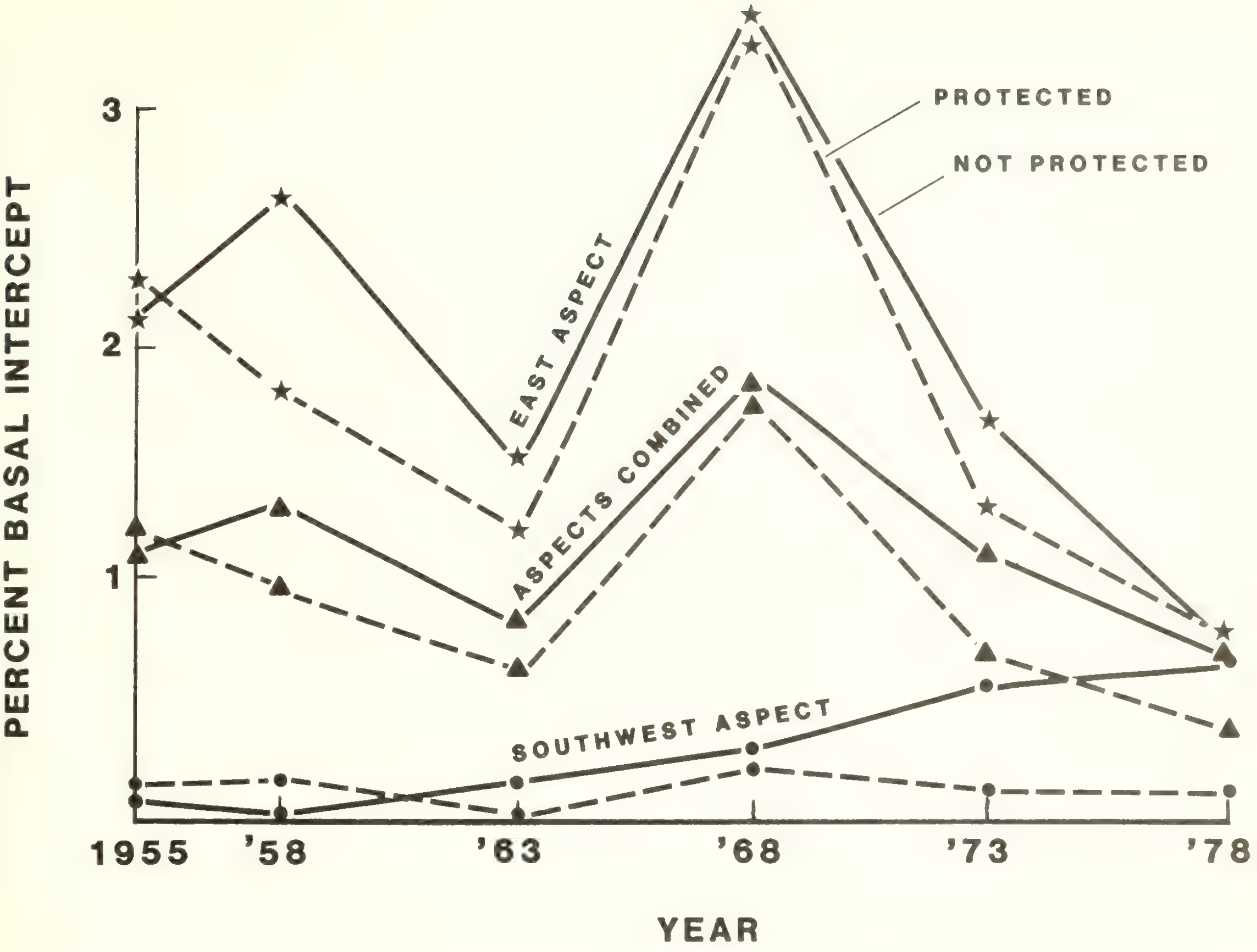

Figure 2.--Percent basal intercept of herbaceous perennials; 1955 to 1978, according to degree of protection and slope aspect.

Table 2.--Mean density (number per 100 ft^2) of herbaceous perennials, excluding Sandberg bluegrass and needle-leaved phlox

	1955	1958	1963	1968	1973	1978
Protected, SW	1.7	1.8	1.4	1.5	7.6	7.8
Browsed, SW	.6	1.1	1.8	3.5	8.0	10.7
Protected, E	4.7	2.3	3.9	4.3	9.4	8.2
Browsed, E	4.9	3.8	7.1	5.8	17.2	17.8
Protected	3.2	2.0	2.6	2.9	8.5	8.0
rowsed	2.8	2.4	4.4	4.6	12.6	14.2
outhwest	1.2	1.4	1.6	2.5	7.8	9.2
ast	4.8	3.0	5.5	5.0	13.3	13.0

The number of species of herbaceous perennials doubled between 1955 and 1978 on both slopes within the exclosure. Outside the exclosure, the increase in numbers of perennial species encountered was of roughly the same magnitude as inside the exclosur (table 3).

Table 3.--Number of species of herbaceous perennials recorded on each sampling date

	1955	1958	1963	1968	1973	1978
Protected, SW	8	7	9	8	13	16
Browsed, SW	3	4	6	6	8	7
Protected, E	9	7	12	12	17	18
Browsed, E	11	10	12	17	15	19

Annual Plant Species

The list of annual plant species encountered during the study remained essentially unchanged. However, populations of individual species fluctuated considerably, as indicated by frequency data. Cheatgrass (*Bromus tectorum* L.) frequency ranged between 90 and 100 percent on all transects in every year sampled except 1968, when it ranged from 90 to 100 percent on southwest slopes but dropped to mean of 68 percent on east slopes.

In addition to the ubiquitous cheatgrass, common annual species on the study are have been bigflower groundsmoke (*Gayophytum diffusum* Torr. & Gray), large-flowered collomia (*Collomia grandiflora* Doug. ex Lindl.), storksbill (*Erodium cicutarium* (L). L'Her.), and bedstraw (*Galium aparine* L. var. *echinospermum* [Wallr.] Farwell). Some annuals were found almost exclusively on specific exposures: common clarkia (*Clarkia rhomboidea* Dougl.) and desert plectritis (*Plectritis macrocera* [T.&G.] Gray); characteristically occupied east slopes; dwarf monkey-flower (*Mimulus nanus* H.&A.) wa found only on the southwest slope, while storksbill and wire-stemmed eriogonum (*Eriogonum vimineum* Dougl. ex Benth.) were common on southwest slopes but very rare c east slopes.

DISCUSSION

The purpose of this study was to learn more about the effects of protection fron deer browsing on the dominant perennial plant species occurring on the Boise River winter range. After 23 years of periodic observations, it appears that changes are only slightly affected by the presence or absence of deer.

Anderson and Holte (1981) cited several recent studies suggesting that forest ar shrub communities may be exceptionally stable in the absence of external disturbance Their data from sagebrush-dominated rangeland in southeastern Idaho suggested that tl population of dominant shrubs had been relatively stable over 25 years of protection from grazing. Voth (1979) found that changes in species numbers and in perennial co were minimal between 1931 and 1977 on plots protected from livestock grazing. Some her data were from winter range areas along the South Fork of the Boise River that w similar to our study area. On the other hand, shrub stands established as a result drastic disturbances (such as wildfire) are often seral, and vegetative composition changes drastically within a decade or two.

In this study, the stands of bitterbrush inside and outside the exclosure have both decreased in density and increased in canopy spread. Thus, the bitterbrush population is thinning but the remaining shrubs are larger. Over the 23-year study, only five new bitterbrush plants have become established on the 0.1 acre (0.04 ha) sampled. If this is representative of the surrounding area, it suggests that approximately two new bitterbrush plants have become established per acre, per year. Bitterbrush reproduction can be expected to be poor where a well-stocked stand of old shrubs is complemented with a dense understory of cheatgrass and scattered herbaceous perennials, all of which provide severe competition and leave few openings for bitterbrush seedling establishment. Furthermore, the lack of livestock grazing (outside the exclosure as well as inside) decreased soil disturbance and encouraged the return of herbaceous perennials.

The slightly smaller increase in canopy cover of bitterbrush inside the exclosure than outside might be expected. This is because old bitterbrush tend to reduce annual twig growth in favor of seed production unless continually stimulated by the browsing of animals. The bitterbrush stands on the study area were mature at the study's start.

The population of rubber rabbitbrush exhibited a much more rapid turnover than the population of bitterbrush; 50 percent of the 24 plants tallied in 1955 had died by 1978, but 73 new plants had become established. More than 200 rabbitbrush seedlings were tallied on the southwest slope outside the exclosure in 1955, none of which survived to the 1958 sampling. In 1968, a total of 170 seedlings were recorded on all transects; 10 years later, 32 percent of these plants were still alive, but most were still very small, having exhibited a mean growth of 1 to 2 inches (2.5 to 5 cm) per year. Survival rates among the 1968 seedlings were 23 percent inside the exclosure, 37 percent outside, 13 percent on southwest slopes, and 39 percent on east slopes.

In southeastern Idaho, Anderson and Holte's (1981) data suggest a rapid turnover in the population of green rabbitbrush (Chrysothamnus viscidiflorus [Hook.] Nutt.), with no evidence of seral replacement of green rabbitbrush after 25 years of protection from livestock grazing.

The measured decrease in basal intercept of herbaceous perennials on east slopes, both inside and outside the exclosure, was due entirely to a decrease in the basal intercept of Sandberg bluegrass. Bluegrass basal intercept decreased 68 percent between 1955 and 1978 (fig. 2). However, the increase recorded in 1968 suggests that climatic variability affects the composition of a plant community and the vigor of individual species within the community. Bluegrass density also decreased on east lopes by 32 percent inside the exclosure and by 43 percent outside. Although the ecrease in density of bluegrass agrees with the measured decrease in basal intercept, he relative accuracy of the density data is uncertain because of the difficulty in istinguishing individual plants of Sandberg bluegrass.

McLean and Tisdale (1972) observed a decrease in Sandberg bluegrass in several 9-year-old exclosures in British Columbia. Neal (1982) noted that heavy, early spring razing by cattle on deer winter range in southern Oregon and northern California educed the cover of all bunchgrasses except Sandberg bluegrass, which increased. Both eal (1982) and McLean and Willms (1982) cite high the value of Sandberg bluegrass as arly spring forage for mule deer.

Data from outside the exclosure show an overall decrease in basal intercept of erbaceous perennials over the 23-year study. However, this was due to the decrease in easured basal intercept of Sandberg bluegrass on the east slope, as mentioned above. n the unprotected southwest slope, total basal intercept increased from 0.24 percent n 1955 to 0.63 percent in 1978, due entirely to an increase in needle-and-thread grass

(Stipa comata Trin. & Rupr.). In 1955, only five needle-and-thread plants were tallie on the 12 southwest slope transects; this number increased to 26 by 1968, and to 66 in 1978.

The smaller increase in density of herbaceous perennials inside the exclosure may be a result of less soil disturbance, which in turn offers fewer favorable locations for the establishment of seedlings than may be available on the area used by deer.

Table 4 shows the overall change in density of the major perennial grasses and forbs between 1955 and 1978. One important change is the decrease in density of balsamroot on both protected and unprotected east slopes. Balsamroot numbers decrease from 23 to 3 and from 16 to 4 on east slopes inside and outside the exclosure, respectively. A general decrease in balsamroot would be important because it is a ver long-lived species and is a valuable forage plant on deer winter ranges. Burrell (1982) found that balsamroot made up from 6 to 22 percent of the diet of mule deer in Washington, with the use of balsamroot increasing as the availability of bitterbrush decreased.

Table 4.--Overall change in density of major species of herbaceous perennials, 1955-1978

	Protected		Browsed
	Slope aspect		
	SW	E	SW
GRASSES			
Agropyron inerme	NC[1]	NC	NC
Poa bulbosa	NC	NC	I[2]
Poa secunda	NC	D[3]	NC
Sitanion hystrix	NC	NC	NC
Stipa comata	I	--[4]	I
Stipa thurberiana	--	--	--
FORBS			
Achillea millefolium	I	--	--
Arabis spp.	I	I	I
Balsamorhiza sagittata	NC	D	--
Delphinium spp.	NC	I	--
Phlox aculeata	D	D	--
BIENNIALS			
Aster canescens	I	NC	I
Erysimum capitatum	--	I	--
Phacelia heterophylla	I	NC	I

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[1] NC = no change.
[2] I = increase.
[3] D = decrease.
[4] -- = did not occur.

CONCLUSIONS

Data obtained from vegetative sampling over the 23-year study showed that deer use, which varied from extremely heavy to light, has not been a significant factor influencing vegetative composition or the trend in plant succession. Specifically, deer use did not prevent an increase in canopy cover or shrub height of bitterbrush, nor did deer use have any effect on the canopy cover or density of rubber rabbitbrush.

Although bitterbrush density decreased, individual bitterbrush shrubs became larger. Yet the shrubs probably are producing less available browse for wintering deer because of height and old age. This will be true especially when snow depth limits access to grass and forb species. The density of herbaceous perennials other than Sandberg bluegrass, balsamroot, and needle-leaved phlox has slowly increased, both inside and outside the exclosure.

Under those circumstances, managers should consider either rejuvenating old bitterbrush shrubs by topping (Ferguson and Basile 1966; Ferguson 1972) or increasing stand density and age class distribution by seeding or planting (Holmgren and Basile 1959; Medin and Ferguson 1980).

PUBLICATIONS CITED

Anderson, Jay E.; Holte, Karl E. Vegetation development over 25 years without grazing on sagebrush-dominated rangeland in southeastern Idaho. J. Range Manage. 34(1): 25-29; 1981.

Burrell, Galen C. Winter diets of mule deer in relation to bitterbrush abundance. J. range Manage. 34(4): 508-510; 1982.

Canfield, R. H. Sampling ranges by the line interception method; plant cover-composition-density-degree of forage use. Res. Rep. 4. Tucson, AZ: U.S. Department of Agriculture, Forest Service, Southwestern Forest and Range Experiment Station (since integrated with Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO); 1942. 28 p.

Ferguson, Robert B. Bitterbrush topping: shrub response and cost factors. Res. Pap. INT-125. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1972. 11 p.

erguson, Robert B.; Basile, Jseph V. Topping stimulates bitterbrush twig growth. J. Wildl. Manage. 30(4): 839-841; 1966.

orsling, C. L.; Storm, E. V. The utilization of browse forage as summer range for cattle in southwestern Utah. Circ. 62. Washington, DC: U.S. Department of Agriculture; 1929. 30 p.

olmgren, Ralph C.; Basile, Joseph V. Range revegetation and deer on the Payette. Idaho Wildl. Rev. 1956 September-October: 10-13.

olmgren, Ralph C.; Basile, Joseph V. Improving southern Idaho deer winter ranges by artificial revegetation. Wildl. Bull. No. 3. Boise, ID: State of Idaho, Department of Fish and Game; 1959. 61 p.

cLean, A.; Tisdale, E. W. Recovery rate of depleted range sites under protection from grazing. J. Range Manage. 25(3): 178-184; 1972.

McLean, A.; Willms, W. Competition between cattle and mule deer on winter range in British Columbia. In: Peek, J. M.; Dalke, P. D., eds. Proceedings of the wildlife-livestock relationships symposium; 1981 April 20-22; Coeur d'Alene, ID. Moscow, ID: University of Idaho, Forest, Wildlife, and Range Experiment Station; 1982: 61-73.

Medin, Dean E.; Ferguson Robert B. A pilot planting trial on a southwestern Idaho deer winter range. Res. Pap. INT-261. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1980. 13 p.

Neal, Donald L. Improvement of Great Basin deer winter range with livestock grazing. In: Peek, J. M.; Dalke, P. D., eds. Proceedings of the wildlife-livestock relationships symposium; 1981 April 20-22; Coeur d'Alene, ID. Moscow, ID: University of Idaho, Forest, Wildlife, and Range Experiment Station; 1982: 479-484.

Shaw, W. M.; Nielson, A. E. Idaho game population census and range study. Completion report for P-R Project 85-R. Boise, ID: Idaho Fish and Game Department; 1951. Processed.

Voth, Annette Sue. Successional patterns of sagebrush-bunchgrass rangeland of the Bois National Forest. Moscow, ID: University of Idaho; 1979. 139 p. Dissertation.

Section 4. Management Strategies

ARTIFICIAL REVEGETATION USING ANTELOPE BITTERBRUSH--A LAND MANAGER'S VIEW[1]

Robert Carpenter[2]

ABSTRACT

Revegetation procedures using antelope bitterbrush (Purshia tridentata) are discussed from a land manager's point of view. Since 1976, approximately 600,000 seedlings have been transplanted on the Arrowrock Front deer winter range of the Boise National Forest.

Volunteers, YACC, seasonal employees, and contract labor have been employed to complete the field work. Items included in this discussion are: acquisition of seed and rearing, grading, storing, field planting, and transplant stock procedures. Survival varied greatly depending on quality of plants, time of planting, and planting method.

INTRODUCTION

In 1976, a major effort to rehabilitate the Arrowrock Front deer winter range using antelope bitterbrush (Purshia tridentata) was initiated. The area is located on the Boise National Forest and lies approximately 18 air miles (29 km) east of Boise, Idaho. Topography is typically steep and dissected. Slope gradients range from 15 to 80 percent. South facing exposures are dominant. Elevation ranges from 3,200 ft (980 m) to 5,200 ft (1592 m). Soils are granitic, coarse textured, and loose, with low waterholding capacity. Annual precipitation averages approximately 19.5 inches (49 cm).

IDENTIFY PLANTING AREAS

The first step in successful big game rehabilitation is to identify and select acceptable planting areas. These sites are frequently the more critical areas for wintering game animals. Data collected by observations during several years of average or more severe winters are necessary to determine the location of these ranges Following this initial screening, the areas should be inventoried to determine soil and vegetative conditions.

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[1] Paper presented at Bitterbrush and Cliffrose Symposium, Salt Lake City, Utah April 13-15, 1982.

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ACQUIRING SEED

The acquisition of seed from plant populations that are adapted to the planting site is extremely important. It is best to acquire seed from plants growing on similar habitat types within the local area. When this is not possible, one should be very careful in selecting seed from unfamiliar seed sources.

The cost of seed is dependent upon such factors as demand, ease of collection, and available seed supplies. A discussion of seed collection may be obtained from various reports (Schopmeyer 1974; Shaw 1981; Plummer and Jorgensen 1978). During the past 7 years, bitterbrush seed costs have ranged from $4.00 per pound ($8.80/kg) to $8.00 per pound ($17.60/kg). All seed lots should be tested for viability and germination before planting. This can normally be completed through state seed laboratories or private seed companies. There are approximately 15,000 seeds per pound (6800/kg) of bitterbrush seed (USDA 1971).

SEEDING OR PLANTING

Once an area has been selected for treatment and seed has been acquired, two planting options are available. Both methods have economic and logistic advantages and disadvantages.

1. Seeds may be planted directly onto the site. For more information on direct seeding refer to Medin and Ferguson (1980).

2. Bareroot or containerized transplant stock can be propagated or acquired and field planted.

Transplant stock can be grown as bareroot or containerized plants.

CONTAINERIZED STOCK

Containerized stock is normally grown under greenhouse conditions. Plants are grown in special mediums composed of peat, vermiculite, and sand. Length of time from seed to plant varies from 5 to 10 months (Ferguson and Monsen 1975). Use of containerized stock on a large scale in Idaho Batholith soils has been thought to be unsuccessful for the following reasons:

1. The soil medium is not compatible with the native soils. The containerized plant medium is "spongy" because of the high peat and vermiculite content and in droughty climates seems to dry more rapidly than the native soils.

2. The roots tend to remain in the potting medium. They do not grow quickly into the native soils. If the potting soil dries out, the roots die.

BAREROOT STOCK

Bareroot stock can be grown in seed beds at a commercial or Forest Service nursery. At the Lucky Peak Nursery, Boise, Idaho, seed is planted either in the late fall (normally October) or in the early spring. The seed is allowed to germinate and grow for one season. Transplants of adequate size can be produced in one growing season.

Figure 1 illustrates possible planting and lifting schedules for year-old stock. Close coordination by field personnel with the nursery is required. Growing periods may vary depending on the location of the nursery.

Lifting Bareroot Stock

	1981			1982												1983			
MONTHS	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A
	P_1					Growing Season							L_1						
	P_2					Growing Season												L_2	
					P_3	Growing Season							L_3						
					P_4	Growing Season												L_4	

P = Time seed is planted
L = Time seedlings are lifted

Figure 1 -- Possible planting and lifting schedules for year-old bareroot stock

At the Lucky Peak Nursery, plants are spring lifted between February 20 and March 10, but may be fall lifted between October 20 and November 10. Fall lifted shrubs can be stored over winter in nursery storage. Fall lifted seedlings may be planted in the late fall or early spring. We have planted shrubs during all months from October through April on the Arrowrock Front winter range. However, planting from November 20 until February 15, is dependent on the soils being thawed. Although it is possible to plant throughout the winter, the ideal time to plant is early in the spring to allow plants to establish an adequate root system. This must be done before the dry summer period. The seedlings should be planted so that they can break dormancy at the same time as the native plants. This allows the seedling the maximum amount of time for root establishment. The time frame for planting is very narrow.

Grading and Packaging

Following lifting, plants are taken into the packing shed where they are graded and packaged. Grading is the process of sorting out the usable from the "cull" plants Variables involved in grading are:

1. Size of the plant stem

2. Size of the root system

3. Branching of the stem

Factor number 3, "branching of the stem," seems to be the best criterion to use for grading antelope bitterbrush. As a general rule, top branching indicates an adequate root system for field planting. Figure 2 illustrates the variability in size of plants lifted from the same seedbed.

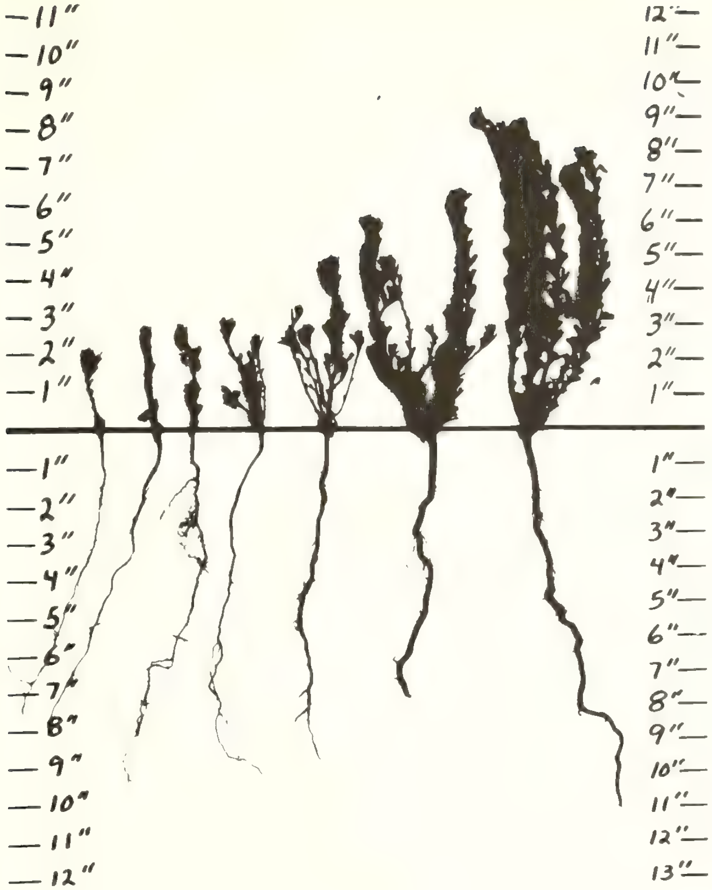

Figure 2. -- Illustrates variability in size of bitterbrush grown in the same seedbed

Packaging is completed at the nursery immediately following the sorting and grading process. Plants are packaged in either bags or crates with spagnum moss used as a packing medium.

Storage of Lifted Plants

Prior to shipment, plants are stored in coolers at the nursery. Plants are stored at temperatures between 28° and 34°F (-2 and 1°C) (Dahlgreen and others 1974).

Wrapping Plants

Seedlings should be removed from storage just prior to planting. Plants in a now cache should be removed 1 day in advance of planting. This is particularly ritical if the daytime temperature is above 50°F (10°C). Plants removed from storge should be dipped in a vermiculite solution and wrapped in wet burlap (Dahlgreen nd others 1974). Plants should not be wrapped more than 2 to 3 days before planting. t is best to wrap the shrubs the night before planting. The warmer the weather, the ore critical this factor becomes. Wrapping should be done where there is no wind, o direct sun, relative humidity is high and temperature is low.

PLANTING (SITE PREPARATION)

Site preparation is the first step in the actual planting process. Completion is reduced by scalping. "Scalping" is the process of removing the vegetation from the area to be planted. Tools used in scalping included McCleods, fire rakes, or hodads (Larson and Milodragoyich 1982). The scalp should be a minimum of 3 ft by 3 ft (.9m by .9m) (Holmgren 1956). It is essential to remove competition for a 1-2 year period. This permits the transplant to establish an adequate root system.

HAND PLANTING

The final and most critical step of the planting process is placing the plant in the ground. The importance of this step cannot be overemphasized. However, if the preceding steps are not completed correctly the plant may already be doomed when planted.

All planting on the Arrowrock Frong has been accomplished with planting bars. These come in a variety of shape and sizes. The most useful bar for this site has been the modified KCB bar. The blade has been modified to a 14 inch (35 cm) blade length. This provides adequate depth for the plants root system and usually prevents plants from being planted "too shallow." The steps in the planting process are shown below. These steps have been taken from the USDA, Forest Service Reforestation Handbook (1971). This method is often referred to as "slit" planting and is not permitted for tree planting in the Intermountain Region. Because of differences between tree and shrub root configuration, slit planting is a desirable planting method for shrubs on the Arrowrock Front. The following procedure is used with the modified KCB bar:

1. Use both hands to drive the bar full length in the ground at the proper angle near the center of the selected spot. Use foot on the step as needed. Repeated efforts may be required in some instances.

2. Withdraw the bar 1 inch (2.5 cm). Open the bottom of the hole by pulling the bar 4 to 6 inches (10-15 cm) toward the body while using the point where the bar enters the ground as a fulcrum.

3. Force the bar into the ground so the tip acts as a fulcrum and push the bar 6 to 8 inches (15-20 cm) away from the body. This should open the top of a rectangular hole approximately 14 x 3 x 2½ inches (35 x 7.5 x 6 cm).

4. Remove the bar from the hole without disturbing the soil faces. Bend over or drop to one knee.

5. Carefully remove one seedling from the carrier, shaking it gently to straighten the roots. Insert the shrub in the hole until the root collar is 2 inches (5 cm) below the soil surface.

6. Raise the shrub so the root collar is level with the soil surface. Make sure the roots are fully extended in a near natural position, not curled or twisted

7. Thrust the bar into the soil 3 inches (8 cm) in front of the shrub while holding the seedling at the proper depth near the center back of the slit. Push the bar forward, forcing dirt into the top of the hole, securing the seedling in place. Release the seedling and stand up.

8. Drive the bar full length into the soil as before at the same point used above. Do not permit the bar to angle into the planting hole.

9. Withdraw the bar 1 inch and pull it 4 to 6 inches (10-15 cm) toward the body. This action closes the bottom of the hole.

10. Force the bar into the ground so the tip acts as a fulcrum and push the bar 6 to 8 inches (15-20 cm) away from the body. This action should close the top of the hole, leaving an open crimp hole.

11. Remove the bar and repeat steps 8, 9, and 10 once or twice so seedling is surrounded by firm soil.

12. Place heel across last crimp hole and step firmly to plug it. Check for firmness and stem position and proceed to next spot.

PLANTING INSPECTION

Major items to observe when completing planting inspections are proper firming of soil around seedling roots and depth of planting. These two factors when not followed as outlined account for 90 percent of all seedling mortality on the Arrowrock Front.

Firmness

Firming the soil around the roots is the most critical step in the planting rocess. Steps 7 through 12 in the planting process need to be strictly adhered to. f the soil is not compacted tightly against the roots, air spaces will remain, lacing tremendous stress upon the plants. Failure to firm the soil around the roots ccounted for 60 percent of the seedling mortality on the Arrowrock Front.

Depth

The second major reason for seedling mortality is improper planting depth. It s much more harmful to plant a seedling too shallow than too deep. The seedling hould be planted with the root collar at the surface of the soil. The proper level s determined by the level of "solid soil", not loose soil (fig. 3). This becomes ore difficult to guage as the steepness of slope increases. As a general rule, the solid soil" level will be the lower or downhill side of the planting hole. When he planting bar is used, an area approximately 6 inches (15 cm) in diameter is isturbed. On steeper slopes this may amount to 2-4 inches (5-10 cm) vertically. his loose soil should not be repacked around the stem as it is usually washed away uring spring storms. Improper planting depth accounts for about 30 percent of all eedling mortality.

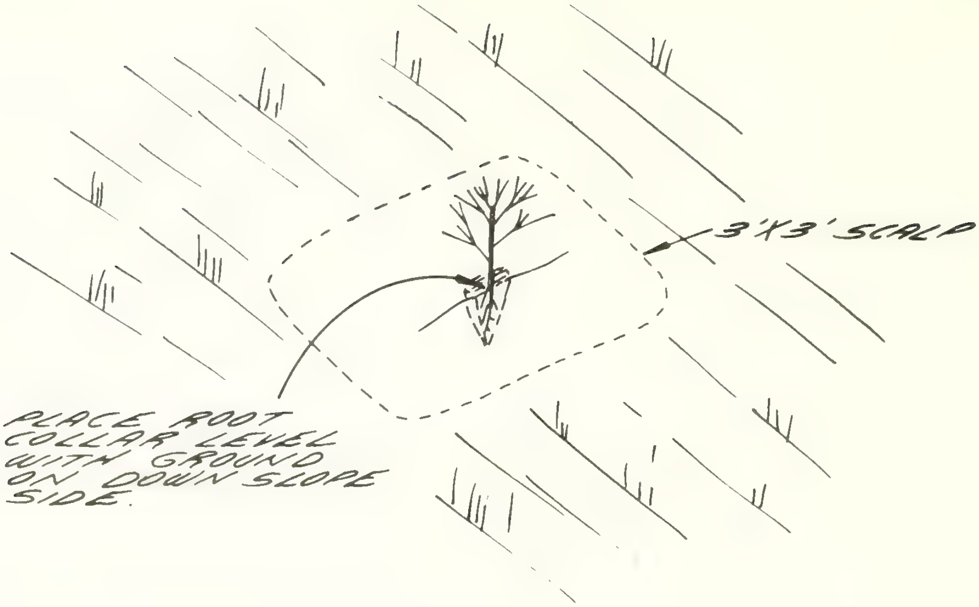

Figure 3 -- Diagram of scalp showing position of planting hole and root collar.

CONCLUSIONS

Large scale transplanting of bareroot shrub seedlings, primarily antelope bitterbrush, has been highly successful on the Arrowrock Front of the Boise National Forest. Between 1976 and 1982, nearly 600,000 seedlings were planted. Careful consideration of the following factors determines the success of planting projects:

1. Planting site selection.
2. Selection of seed adapted to site.
3. Timing of planting.
4. Grading of plants.
5. Storage and handling of lifted plants.
6. Planting practices.

PUBLICATIONS CITED

Dahlgreen, A. D.; Ryker, R. A.; Johnson, D. L. Snow Cache seedlings storage: successful systems. Gen. Tech Rep. INT-17. Ogden, UT: U. S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1974. 12 p.

Ferguson, R. B.; Monsen, S. B. Research with containerized shrubs and forbs. In: North American containerized forest tree seedling symposium: proceedings; 1974 August 26-29; Denver, CO. Great Plains Agriculture Council Publication 68; 1975: 349-358.

Holmgren, Ralph C. Competition between annuals and young bitterbrush (Purshia tridentata) in Idaho. Ecology. 37(2); 370-377; 1956.

Larson, John; Milodragovich, Eli. Catalog for hand planting. Missoula, MT: U. S. Department of Agriculture, Forest Service, Equipment Development Center, 1982. 33 p.

Medin, D. E.; Ferguson, R. B. A pilot planting trial on a southwestern Idaho deer winter range. Res. Pap. INT-261. Ogden, UT: U. S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1980. 13 p.

Plummer, A. P.; Jorgensen, K. R. Harvesting, cleaning and storing seed of western shrubs. In: Western Forestry Council and Intermountain Nurserymens Association; Nursery Conference and Seed Proc. Workshop: proceedings; Eureka, Ca: 1978: D65-75.

Schopmeyer, C. S., Technical Coordinator. Seeds of woody plants in the United States. Agriculture Handbook 450: 1974. 883 p.

Shaw, Nancy. Propagating and outplanting shrubs on mine sites. In: Stelter, L. H. DePuit, E. J. and Mikol, S. A., Technical Coordinator. Shrub establishment on disturbed arid and semi-arid lands symposium. proceedings; 1980 December 2-3: Laramie, WY.; Cheyenne, CY: Wyoming Game and Fish Department; 1981: 47-56.

U. S. Department of Agriculture, Washington, D. C.,; U. S. Department of Agriculture, Forest Service; Reforestation Handbook Amendment Number 5. Washington, D. C.; U. S. Department of Agriculture, Forest Service; 1971.

SEEDING ANTELOPE BITTERBRUSH WITH GRASSES ON SOUTH-CENTRAL IDAHO RANGELANDS--A 39-YEAR RESPONSE

Stephen B. Monsen and Nancy L. Shaw[2]

ABSTRACT

The response of a 39-year old seeding of antelope bitterbrush and perennial grasses in south-central Idaho is discussed. The effects of livestock grazing upon shrub establishment and survival and the composition of the understory plants is presented. Natural establishment of shrub seedlings is also reported.

INTRODUCTION

Shrub seedings on western rangelands were initiated in the early 1940's and 1950's following revegetation studies in Idaho (Holmgren and Basile 1959), California (Hormay 1943), Washington (Brown and Martinsen 1959), and Utah (Plummer and others 1957). Antelope bitterbrush (*Purshia tridentata*) was soon recognized as a useful species to plant on game and livestock ranges. Nord and others (1967) found that seeds from this shrub could be easily collected, processed, and planted. Holmgren (1954) reported that the seeds germinated uniformly and the seedlings were quite vigorous.

Several factors caused erratic results from early shrub seedings. Problems often resulted from the lack of satisfactory planting equipment. Competition from annual weeds and established perennials reduced shrub seedling survival and establishment (Holmgren 1956; Hubbard 1956). Holmgren and Basile (1959) determined that rodent depredation of seeds and small seedlings was also a major deterrent to the establishment of antelope bitterbrush and other shrubs. In addition, livestock, rabbit, and game animal grazing was destructive to new plantings (Plummer and others 1966). Although such factors hampered early plantings, methods were developed to minimize these problems and facilitate seeding of shrubs on large acreages.

In the mid-1940's, agricultural drills and seeders were adapted to plant shrubs and grasses on game and livestock ranges. The equipment was modified to plant grass and shrub seed in separate drill rows to reduce competition between the two classes of plants. Numerous plantings of antelope bitterbrush and introduced grasses were established in south-central Idaho in the 1940's and 1950's. The seeded species have since reached maturity. Consequently, this study was instigated to evaluate the success of mixed plantings, particularly (1) the ultimate survival of seeded antelope bitterbrush, (2) recruitment of new antelope bitterbrush plants, and (3) the composition and herbage production of the seeded and native species.

METHODS

In summer 1942, a wildfire burned approximately 1,200 acres (486 ha) of rangeland in the Willow Creek and Case Creek drainages of the Mountain Home Ranger District, Boise National Forest, Idaho. Prior to burning, the sites supported a mixed stand of mountain big sagebrush (*Artemisia tridentata* ssp. *vaseyana*), antelope bitterbrush, and

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[1] Paper presented at Bitterbrush and Cliffrose Symposium, Salt Lake City, Utah; April 13-15, 1982.

[2] Botanists at the USDA-Forest Service, Intermountain Forest and Range Experiment Station's Forestry Sciences Laboratory in Boise, ID.

various bunchgrasses. In October 1942, about 45 acres (18 ha) within the Case Creek drainage were seeded with a tall upright form of antelope bitterbrush and a grass-forb mixture (table 1). The site was planted by coupling one 10-ft (3.1 m) and two 6-ft (1.8 m) John Deere double disc drills together. Seeds of the herbs were mixed together and planted with these drills (fig. 1). The antelope bitterbrush seed was planted separately from the herbs by blocking off the outside portion of one grain drill box and seeding antelope bitterbrush through one drop of the drill. Thus, the grasses and broadleaf herbs were seeded in a strip approximately 22 ft (6.7 m) wide. Antelope bitterbrush was planted in single rows spaced about 22 to 26 ft (7 m) apart. For the first 2 years after planting, the site was protected from livestock grazing. Thereafter, cattle grazed the area either in the spring or early summer.

Table 1.--Seeding mixture--Case Creek planting, October 1942

Species seeded	Seeding Rate
	lbs/acre
Agropyron desertorum	3.00
Arrhenatherum elatius	1.00
Bromus inermis	1.00
Poa bulbosa	1.00
Melilotus officinalis	.25
Purshia tridentata	1.60

In 1946, a 1-acre (0.41 ha) livestock-proof exclosure was erected to determine the ffects of livestock use on the seedings. Ten drill rows of antelope bitterbrush, each pproximately 133 ft (40.5 m) long, were included within the exclosure. Counts and measurements of all antelope bitterbrush plants in each row were recorded from 1949 through 1951. Similar data were not recorded for seeded shrubs outside of the exclosure. However, field observations were recorded during each of the first 7 years following planting. In 1981, the exclosure site was resampled 39 years after planting. Three outside areas similar to the exclosure in aspect, soil conditions, and orientation of the exclosure were selected for study at this time. Each outside area included five adjacent seeded rows of antelope bitterbrush, each 133 ft long.

All antelope bitterbrush plants within each drill row were individually measured o determine their maximum height and maximum crown. The number of seeded shrubs to ccur in the protected and grazed areas are presented as plants per acre. A Student's t test was used to test for significant differences between average number of seeded shrubs per row in the exclosure and on the grazed sites (Sokal and Rohlf 1969).

Duncan's Multiple Range Test was used to determine differences among means for shrub heights and crowns (Steel and Torrie 1960).

In 1981, the cover and herbage production of all herbaceous and woody plants was estimated using 10.8 ft^2 (1 m^2) square plots. Within each of the four study areas, four antelope bitterbrush plants were randomly selected from each of the five rows. A 10.8 ft^2 plot was located directly beneath each shrub. Four additional plots of the same size were established adjacent to each of these shrubs in a line perpendicular to the shrub row. The plot centered beneath the shrub was identified as quadrat 1. Successive quadrats away from the shrub were numbered in sequence from 2 through 5. This positioning allowed for comparison of the influence of the overstory shrub on the understory composition and production as a function of distance from the shrub.

The annual herbage production of each species within the frame was determined by ocular estimate. Plants in every fifth set of plots were clipped and weighed as a check against the ocular estimates. Clipped samples were then air dried and reweighed to provide dry weight conversion factors. Live ground cover for each species was determined by estimating the area occupied by the vertical projection of stems and foliage. The percent cover provided by litter and bare ground was also estimated and recorded. Production data were expressed in grams of herbage per meter square plot. Duncan's Multiple Range Test was used to determine differences among the means of species densities and yields for all quadrat positions both within and between the protected and grazed areas.

RESULTS AND DISCUSSION

In 1949, the first counts of antelope bitterbrush plants within the exclosure we made 7 years after planting (table 2). There was an average of one antelope bitterbrush plant per 7.6 linear ft (2.3 m) of seeded row. More than 99 percent of the seedlings recorded in 1949 survived, counting as mature plants in 1981. In the grazed area, a mean of one antelope bitterbrush shrub per 12 ft (3.7 m) of planted row survived in 1981. Compared to the exclosure about 36 percent fewer shrubs become established in the grazed areas.

Table 2.--Numbers of antelope bitterbrush plants to establish and survive--Case Creek, 1941 seeding.

	Exclosure site				Grazed areas			
	1949	1950	1951	1981	1949	1950	1951	1981
Mean number plants/ 133 ft row	17.5	17.5	17.2	17.2	--	--	--	11.0
Frequency (linear feet of row/plant)	7.6	7.6	7.7	7.7				12.0
No. plants/acre	197	197	194	194				124
Percent survival	100	100	99.5	99.5				--

Livestock grazing, although regarded as low or moderate in regards to the amount of grass removed, caused a decrease in the number of shrubs to establish and persist. Few game animals graze the study areas and have little influence on plant responses. Field records report that major losses of shrub seedlings to livestock grazing had occurred by 1946 when the plants were less than 4 years old. Field observation summarized by Holmgren in 1946 reported that: "The palatability of the shrubs soon became evident under light to moderate use as determined by the utilization of crested wheatgrass. The bitterbrush was grazed heavily and the removal of all current growth was not unusual."[3]

Apparently cattle grazing continued to be detrimental to shrub survival and plant vigor in grazed areas even after 1946. If the number of antelope bitterbrush plants was approximately uniform throughout the planted area in 1946, then differences in plant numbers recorded in 1981 in the grazed and protected areas could be due to the influence of continued livestock grazing. Seedling losses attributable to livestock grazing were observed from field inspections for 5 to 7 years after planting[3]. By 1949, cattle grazing had significantly reduced the size of the existing plants (table 3); plants growing within the exclosure were nearly double the size of the grazed plants. Undoubtedly annual grazing had a cumulative effect upon the small plants. Shrub seedlings that survived for the first 5 to 7 years apparently were

Table 3.--Measurements of 7-year old antelope bitterbrush plants in grazed and protected sites--Case Creek, 1949.

Treatment	Height	Crown diameter	Stem diameter	Yield
	----------inches	------------		g/plant
Grazed areas	8.1^{a}[1]	7.0^{a}	0.3^{a}	5^{a}
Exclosure	15.8^{b}	13.2^{b}	0.3^{a}	35^{b}
Alone[2]	19.3^{c}	19.2^{c}	0.5^{b}	60^{c}
With competition[3]	14.6^{b}	11.3^{b}	0.3^{a}	25^{b}

[1] Figures in the same column not sharing the same letter superscript are significantly different at the .05 percent confidence level.

[2] Selected shrubs growing without other plants within a 30-inch (76.2-cm)radius.

[3] Selected shrubs growing with other plants present within a 30-inch (76.2-cm) radius.

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[3] Holmgren, R. C. Boise, ID: Data on file at the Forestry Sciences Laboratory; 1946.

able to persist even though cattle grazing continued annually for nearly 40 years. A satisfactory stand developed even though the young plants were heavily browsed each year during the period of establishment.

Competition from other shrubs and herbs also affected the growth of the young antelope bitterbrush plants. Shrub seedlings encountered in locations where no other plants occurred within a 30-inch (76.2 cm) radius were significantly larger than seedlings that existed with competition (table 3). Hubbard and others (1962) reported that crested wheatgrass plants found growing within 2 ft (0.60 m) of young antelope bitterbrush reduced shrub vigor and size. At a separate planting established in the Willow Creek drainage in 1948, many antelope bitterbrush seedlings succumbed to intens competition from annual weeds during the first growing season. Heavy losses occurred even in areas protected from livestock grazing[4].

In most areas throughout the Case Creek planting, antelope bitterbrush was able t establish and persist with the seeded herbs. Seeding the herbs in separate rows from the shrubs satisfactorily reduced competition between the seedlings. Seeded shrubs were uniformly distributed throughout the seeded rows. Plants were not clumped together, but appeared in a regular pattern. Spacing the seeded row of bitterbrush approximately 10 inches (25 cm) from the adjacent row of seeded grass provided a satisfactory 20-inch (50-cm) buffer for establishment of the shrub seedlings. Giunta and others (1975) found that a 24-inch (60 cm) width is required to establish shrubs i areas dominated by annual cheatgrass (*Bromus tectorum*). Rangelands can be successfully seeded in this manner unless a large number of residual plants remain after burning or other treatments. An influx of annual weeds can also reduce shrub seedling survival.

The combined effects of biological and climatic influences upon shrub seedling emergence and survival were significant. The ultimate attainment of mature plants was extremely low compared to the number of seeds planted. Assuming 24,000 antelope bitterbrush seeds per acre were dispersed in the Case Creek seeding, a return rate of only 0.008 percent was attained in the exclosure. This amounts to about one plant for every 120 seeds planted. Under these conditions approximately 12 seeds per linear ft (31 cm) must be planted to assure the attainment of one shrub per 10 ft (3.1 m) of seeded row. This amount must be increased if minimal grazing or other impacts are expected. However, increasing the seeding rate will not always compensate for expect losses. Competition, drought, or rodent damage may result in the death of all seedlings regardless of the amount of seed planted. Any disruption of new seedings c seriously affect the success of the planting.

VEGETATIVE RESPONSE TO GRAZING, PROTECTION, AND SPACING OF THE SEEDED SHRUB ROWS

Seeded Antelope Bitterbrush

Antelope bitterbrush plants growing in the grazed areas have been moderately browsed by cattle. However, grazing of mature plants has not seriously interfered wi plant growth (table 4). By 1981, shrubs within the exclosure were approximately 15 percent larger in both height and crown spread than those outside the exclosure. Grazing of the shrubs has reduced their size and confined the leader growth into a mo compact area. A major portion of the shrubs have now grown out of the reach of the cattle. However, grazed plants remained vigorous and productive. Plants within the exclosure are widely branched and provide a more open canopy.

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[4] See footnote 1.

Table 4.--Average plant height and crown diameter of grazed and protected shrubs, Case Creek, 1981.

Sampling area	Plant height	Crown spread
	inches	
Exclosure	73.9^{a}[1]	100.6^{a}
Grazed area		
Sampling site 1	61.9^{b}	82.7^{b}
Sampling site 2	58.6^{bc}	82.4^{bc}
Sampling site 3	68.2^{c}	88.4^{c}

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[1] Figure in the same column sharing the same letter superscript are not significantly different at the 0.05 percent confidence level.

It is important that seeded antelope bitterbrush be able to persist through natural regeneration. To perpetuate themselves, new shrub seedlings must be able to establish amid the understory plants. Most seeded grasses, including desert wheatgrass (*Agropyron desertorum*), are highly competitive and may reduce the recruitment of bitterbrush seedlings. Since the Case Creek area was initially seeded in 1942, approximately 205 new shrubs per acre (506 shrubs per ha) have become established by natural reseeding within the exclosure. In the grazed areas 149 new shrubs per acre (368 plants per ha) have become established. The number of new shrubs found in the grazed areas is significantly lower than found in the exclosure site. The plants originated from seed produced by the mature shrubs that were established from the 1942 seeding. The new shrubs occur throughout the strip where grasses were planted. The entry of shrub seedlings has been slow, yet the seedlings have been able to establish amid the seeded and native bunchgrasses.

Native Shrubs

The number and production of mountain big sagebrush and rubber rabbitbrush *Chrysothamnus nauseosus*) appear to be influenced by the presence of the seeded ntelope bitterbrush. Both understory shrubs occupy less cover in quadrat number 1, eneath the canopy of the seeded bitterbrush, than in the other quadrats (table 5). The percent ground cover and production of sagebrush and rabbitbrush tend to increase ith increasing distance from the bitterbrush rows. Both shrubs attain their maximum ensity in the open areas between the seeded rows of antelope bitterbrush. Ground over for these two shrubs within and outside the exclosure was less than 10 percent or any quadrat position. In most instances, no significant difference in cover or erbage production is recorded for similar quadrat positions within or outside of the xclosure. The presence of seeded desert wheatgrass has also been important in ontrolling the invasion of these woody species. Seeding antelope bitterbrush rows at loser row spacings may be a means to control the reinvasion and density of mountain ig sagebrush and rubber rabbitbrush.

Table 5.--Ground cover for grazed and protected sites recorded by meter quadrat portions--Case Creek, 1981

Species	Exclosure site					Grazed site				
Quadrat positions-	1	2	3	4	5	1	2	3	4	5
	Percent									
Seeded shrubs										
Purshia tridentata	38.0	2.8	0.6	1.6	3.5	51.2	3.9	0.2	--	--
Native shrubs										
Artemisia tridentata ssp. *vaseyana*	4.31	7.4	4.2	9.5	9.5	5.9	8.6	8.9	8.7	8.6
Chrysothamnus nauseosus	--	--	1.3	.3	--	--	.2	--	.1	--
Native forbs										
Lupinus argenteus	2.7	2.4	2.2	5.0	7.0	1.3	1.9	2.8	3.3	4.2
Montia perfoliata	2.2	--	--	--	--	--	--	--	--	--
Other perennials	--	--	--	1.6	.5	--	--	--	--	--
Annuals	3.7	--	--	--	--	.2	.1	.4	.2	.3
Seeded grasses										
Agropyron desertorum	20.7	23.6	22.9	18.1	20.0	16.7	15.3	14.6	14.3	13.8
Poa bulbosa	3.3	6.2	9.0	11.1	7.9	2.7	5.1	7.0	7.9	8.8
Native grasses										
Festuca idahoensis	1.4	1.5	2.1	4.7	4.0	1.2	2.1	3.1	3.1	3.5
Poa secunda	--	.6	1.5	1.7	.3	.4	.3	.2	.4	.6
Sitanion hystrix	3.0	1.0	1.7	1.1	2.5	.8	.1	.6	.1	.6
Litter and moss	65.1	59.5	56.5	54.2	50.0	80.2	47.3	46.5	46.9	45.8
Bare ground	3.3	6.4	9.5	12.3	8.4	4.1	23.0	25.4	26.1	27.4

Broadleaf Herbs

Cover and production of perennial forbs was approximately 50 percent greater in the exclosure than in the grazed areas (table 6). Silvery lupine (Lupinus argenteus), arrowleaf balsamroot (Balsamorhiza sagittata) and aster (Aster spp.) are the dominant forbs in all areas. The presence and importance of these three perennials increased with increased distance from the seeded shrubs. These plants did better in the open without the shading influence of antelope bitterbrush. In contrast, the production and percent ground cover of shade tolerant Montia perfoliata decreased with distance from the overstory shrubs.

Seeded Grasses

The density and herbage production of desert wheatgrass was not reduced by the overstory influence of antelope bitterbrush (tables 5, 6). Significant differences in cover by this species did not occur among quadrats positions. Ground cover provided by desert wheatgrass was approximately 28 percent less outside the exclosure than within the exclosure. In addition, the outside areas produce 62 percent less herbage. Grazing reduced the live cover and significantly decreased grass vigor. Yet, desert wheatgrass has been able to persist as the dominant understory species in the grazed area. It appears practical to improve the production of desert wheatgrass by decreasing the spacing between the shrub rows. However, the optimum spacing for bitterbrush is not known.

Bulbous bluegrass (Poa bulbosa) responded quite differently from desert wheatgrass to the presence of overstory shrubs. This short-lived perennial maintained greater cover and herbage production in the openings than as an understory plant. A similar pattern was recorded for the grazed and nongrazed sites. Protection from grazing resulted in slightly higher cover and yield figures, although the differences were not significant.

Native Grasses

The ground cover and herbage yields for both Idaho fescue (Festuca idahoensis) and Sandberg bluegrass (Poa secunda) were significantly greater in the quadrats located away from the seeded shrubs. These two grasses require open conditions to fully develop. Squirreltail (Sitanion hystrix) responded oppositely. Plants located directly beneath the shrubs were more productive. The native grasses were slightly favored within the exclosure. However, plant composition did not differ significantly for any quadrat within or outside the exclosure.

Litter and Bare Ground

In both the grazed and nongrazed areas, the accumulation of litter was significantly greater at a .05 percent confidence level beneath the seeded shrubs than in any other quadrat both within and outside the exclosure (table 5). Litter in quadrat 1 was 65 percent for the exclosure site and 80 percent for the same position in the grazed area. Within the exclosure the percent litter in quadrats two through five was similar, although significantly lower than for quadrat one. In areas outside the exclosure a similar pattern was recorded. However, the percent litter outside the exclosure was less in quadrat positions 2 through 5 in comparison to each similar quadrat position within the exclosure.

The average percent of bare ground was quite low for all quadrats within the exclosure. Quadrat 1 averaged about 3 percent bare ground. This figure increased with distance from the shrub. Quadrats in the grazed areas had a significantly greater

Table 6.--Herbage yields for grazed and protected sites recorded by meter quadrat positions--Case Creek, 1981

	Exclosure site					Grazed site				
Species Quadrat positions:	1	2	3	4	5	1	2	3	4	5
	gr/m^2 plot									
Seeded shrubs										
Purshia tridentata	440.0	14.3	2.7	9.3	51.3	702.0	39.5	1.3	4.2	--
Native shrubs										
Artemisia tridentata ssp. *vaseyana*	39.5	58.8	27.6	67.8	81.3	44.0	80.4	68.6	64.1	55.1
Chrysothamnus nauseosus	--	--	.5	1.5	--	--	.2	--	1.4	--
Native forbs										
Lupinus argenteus	12.0	9.4	10.1	20.4	32.7	7.7	7.8	12.6	16.6	18.6
Montia perfoliata	2.9	--	--	--	--	--	--	--	--	--
Other perennials	--	--	--	11.7	20.3	.7	.2	.6	.8	.1
Annuals	.7	--	--	--	--	--	--	--	--	--
Seeded grasses										
Agropyron desertorum	174.3	172.5	174.6	110.6	130.1	112.2	90.6	90.1	81.5	80.7
Poa bulbosa	3.2	4.3	6.3	8.1	7.5	2.3	3.1	5.2	5.8	6.9
Native grasses										
Festuca idahoensis	2.6	3.5	3.5	8.1	7.7	1.9	3.8	5.5	5.8	10.4
Poa secunda	--	1.3	2.1	1.5	.7	.7	--	.3	.7	.5
Sitanion hystrix	11.5	2.1	6.5	3.7	7.0	2.1	.2	.9	.2	1.1
Total understory vegetation	246.5	251.9	231.2	233.4	287.3	171.6	186.3	183.8	176.9	173.4
Total vegetation	686.5	266.2	233.9	242.7	338.6	873.6	225.8	185.1	181.1	173.4

percentage of bare ground than similar quadrats within the exclosure. Quadrat readings taken beneath the seeded shrubs were similar in the grazed and ungrazed area. However, the percent bare ground was significantly higher in all other quadrats in the grazed areas when compared to the protected site. The percent bare ground in quadrat positions 2 through 5 was similar in the grazed sites, but much higher than for quadrat 1.

CONCLUSIONS AND IMPLICATIONS

Seeding grass and shrub seeds in separate drill rows is a practical method of reducing competition between antelope bitterbrush and perennial grass seedlings. Grass rows should not be planted closer than 12 to 15 inches (30 to 38 cm) from the seeded shrub rows. A wider spacing of about 24 to 30 inches (60 to 76 cm) is more beneficial.

Few shrub seeds become established and develop into mature plants even when this method of seeding is used. However, only a small return is required to produce a satisfactory stand. Care should be given to assure that seeds are properly distributed and positioned in the soil. Livestock grazing should be curtailed for 1 to 4 years to allow shrub seedlings to establish. Thereafter, grazing should be carefully regulated to avoid destruction of the young plants. Established stands of desert wheatgrass limit the natural regeneration of antelope bitterbrush. In addition, moderate grazing by cattle in the spring and summer months also reduces shrub seedling establishment.

The presence and density of a bitterbrush overstory control the composition and yields of understory herbs and smaller woody plants. The shading provided by erect forms of antelope bitterbrush enhances the production of shade tolerant species. The production of desert wheatgrass is increased while the yields of Sandburg bluegrass and Idaho fescue are decreased. Shade tolerant broadleaf herbs also respond positively to the canopy coverage. However, certain important forbs require open conditions to attain maximum productivity. Tall antelope bitterbrush plants reduce the density of both mountain big sagebrush and rubber rabbitbrush. When seeded with competitive understory grasses, antelope bitterbrush can be used to control these two woody species.

PUBLICATIONS CITED

Brown, Ellsworth R.; Martinsen, Charles F. Browse planting for big game in the State of Washington. Biol. Bull. 12. Olympia: Washington Game Department; 1959. 63 p.

Giunta, Bruce C.; Christensen, Donald R.; Monsen, Stephen B. Interseeding shrubs in cheatgrass with a browse seeder-scalper. J. Range Manage. 28(5): 398-402; 1975.

Holmgren, Ralph C. A comparison of browse species for revegetation of big-game winter ranges in southwestern Idaho. Res. Pap. 33. Ogden, Utah: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1954. 12 p.

Holmgren, Ralph C. Competition between annuals and young bitterbrush. Ecology (2): 370-377; 1956.

Holmgren, Ralph C.; Basile, Joseph V. Improving southern Idaho deer winter ranges by artificial revegetation. Wildlife Bull. 3. Boise, ID: Idaho Fish and Game Department; 1959. 61 p.

Hormay, A. L. Bitterbrush in California. Res. Note No. 34, Berkeley, CA: U.S. Department of Agriculture, Forest Service, California Forest and Range Experiment Station; 1943. 12 p.

Hubbard, Richard L. The effects of plant competition upon the growth and survival of bitterbrush seedlings. Forest Res. Note 109. Berkeley, CA.: U.S. Department of Agriculture, Forest Service, California Forest and Range Experiment Station; 1956. 9 p.

Hubbard, Richard L.; Zusman, Pinhas; Sanderson, Reed H. Bitterbrush stocking and minimum spacing with crested wheatgrass. Calif. Fish and Game 48(3): 203-208; 1962.

Nord, Eamor C.; Schneegas, Edward R.; Graham, Hatch. Bitterbrush seed collecting--by machine or by hand. J. Range Manage. 20(2): 99-103; 1967.

Plummer, A. Perry; Jensen, Robert L.; Stapley, Homer D. Job completion report for game forage revegetation project W-82-R-2. Info. Bull. 1956-57. Salt Lake City, UT: Utah State Department Fish and Game; 1957. 128 p.

Plummer, A. Perry; Christensen, Donald R.; Monsen, Stephen B. Highlights, results and accomplishments of game range restoration studies. Pub. 67-4. Salt Lake City, UT: Utah State Department of Fish and Game; 1966. 45 p.

Steel, Robert. G. D.; Torrie, James. H. Principles and procedures in statistics. New York: McGraw-Hill; 1960. 481 p.

Sokal, Robert R.; Rohlf, James F. Biometry the principles and practice of statistics in biological research. San Francisco: W. H. Freeman and Company; 1969. 776 p.

POTENTIALS FOR THE MANAGEMENT OF BITTERBRUSH HABITATS BY THE USE OF PRESCRIBED FIRE[1]

Charles H. Driver[2]

ABSTRACT

Observations on the results of prescribed fire and wildfire in ponderosa pine-bitterbrush-pinegrass habitats indicate potentials for use in managing antelope bitterbrush. Prescribed burns in early spring and fall when soil moisture was high resulted in vigorous sprouting, whereas hot burns resulted in seedling establishment.

INTRODUCTION

Reports on the ecological characteristics of antelope bitterbrush (*Purshia tridentata* (Pursh) DC.) with respect to its reaction to fire appear to be diverse. Have we misinterpreted the true fire ecology of this species and thereby possibly overlooked a tool for managing this important shrub?

Fire is commonly reported (Hormay 1943; Billings 1952) to be very destructive to antelope bitterbrush, practically removing it from its dominant position within the plant community of a typical habitat. However, on some occasions (Nord 1965), it has been observed that a small percentage of the plants recover by sprouting after burning under the most "favorable conditions." On these rare occasions not more than 30 percent of the burned plants give rise to vegetative sprouts, most of which succumb before the end of the first growing season. Moreover, a few reports in the literature indicate that in some areas of its natural range, populations of antelope bitterbrush have exhibited abilities to sprout reasonably well following burning. In fact, Clark (1979) reports 30 to 50 percent of the plants of this species sprouted after being burned in eastern Oregon. In addition, Blaisdell (1953) reported individual plants tended to continue to give rise to sprouts after reburning.

My limited observations (Driver and others 1980) on the response of antelope bitterbrush to prescribed fire directed me to the question: How can a dominant plant species of a pristine climax vegetational community with a known history of frequent fire occurrence not express characteristics that ensure its survival and perpetuation?

To investigate the possibility of using fire as a management tool for the culture of antelope bitterbrush one should examine the status of our knowledge on the subject of prescribed fire as covered by Martin and Driver (this proceedings). In addition, to accomplish the use of fire as a management tool we should examine Barney's (1975)

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[1] Paper presented at the Bitterbrush and Cliffrose Symposium, Salt Lake City, Utah, April 13-15, 1982.

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definition of fire management as the "integrating of fire related biological, ecological, physical and technological information into land management to meet a desired objective." I will follow this with Wright and others' (1979) statement on fire as a tool of management: "One of the most fruitful areas within which to practice these concepts is in that part of our wildlands used for range and wildlife purposes."

These statements establish my objectives in applying the ecological characteristics of this important shrub species in relation to fire, to the need for improving the condition of critical winter range for mule deer.

My initial observations (Driver and others 1980) on the abilities of antelope bitterbrush to sprout following an early spring prescribed fire triggered my interest in this subject.

Table 1 shows the surprising range of 40 to 100 percent of the burned bitterbrush plants sprouted vigorously following prescribed fires within the ponderosa pine-bitterbrush habitat in the early spring. The study area was the Entiat River drainage designated as South, located 20 miles (32.19 km) north of Wenatchee, Wash. The natural fire frequency of the study site was determined to be as low as 6.5 to 10 years during an 80-year period before white people frequented the area. When similar prescribed fires were tried, however, in the same area in the fall, bitterbrush sprouting was only observed to range from 0 to 5 percent. In addition, a survey of all bitterbrush plants within a 35 acre (14.16 ha) area within a large summer wildfire site indicated only 5 percent of the burned plants exhibited vigorous sprouting 3 years after the fire. This site was in the vicinity of the prescribed fire area (South); the wildfire had occurred 2 years previously.

The effects of fires on seedling establishment were evaluated. Observations were conducted in the same general area indicated as South in table 1, in which ponderosa pine fuels resulting from precommercial thinning operations had been piled and burned in early fall. Within the charred-remains areas, ranging from 1/100 to 1/50 acre (40.47 to 80.94 m^2), all vegetation including pinegrass (*Calamagrostis rubescens* [Buckl.]) had been completely destroyed. Three years after the burns, individual seedlings were observed at the density equal to 300 seedlings per acre (table 2). The seedling establishment on the spring prescribed fire plots indicated a density of only 50 per acre (124 per ha).

Table 1. Relative effects of prescribed burns and wildfire on sprouting of antelope bitterbrush.

Season of burn	% Sprouting range plants	Precipitation pattern	Location
Spring	50-88	Spring snow	North
Fall	0-74	Fall rain	site
Spring	40-100	Spring snow	South
Fall	0-5	Dry fall	site
Summer	3	Dry summer	South site

Table 2. Relative effect of prescribed burns and wildfire on antelope bitterbrush seedling establishment.

Type of fire	Season of fire	Average density/acre
Pile and burn	Fall	300
Prescribed burns	Spring	50
	Fall	105
Wildfire	Summer	18 of 20 plants flowering at 3 years and seeding at 5 years

Because the fall burns appeared not to be conductive to bitterbrush sprouting on these South study sites, soil and live plant moisture were probably limiting factors. Typically, no measurable rainfall occurred in this area for the 60 day summer period. A similar habitat and area with a known early fall rain pattern, some 70 miles (112.65 km) north of the Entiat site, located west of Winthrop, Wash., was brought to my attention by the fuels manager officer of the USDA Forest Service. The Winthrop District fuels management group had conducted a series of spring and fall prescribed burns in the ponderosa pine/bitterbrush/pinegrass habitat type over a similar 3 year period.

We surveyed the results of these prescribed fires on bitterbrush sprouting and seedling establishment. On transects one chain wide (66 ft or 20.12 m) progressing entirely across the widest dimension of the burned area, all bitterbrush plants were observed. The presence and absence of sprouting was noted on all burned plants as well as the occurrence of seedlings. The burned stands ranged from 10 to 30 acres (4.05 to 12.14 ha). A summary of the results is noted as the North location in table 1 and as fall burns in table 2. Prescribed fire in the North sites apparently yielded similar results to that of the South sites with relatively high percentages of burned plant sprouting after the spring burns. However, the fall burns tended to result in higher percent sprouting than similar burns in the South site.

DISCUSSION AND CONCLUSIONS

The data in table 1 from the observed sites indicate that prescribed burns conducted in the early spring, when the soil and live plant moisture appear to be high, tended to result in more than half of the plants giving rise to vigorous vegetative sprouting.

Prescribed burning in the fall, especially at the South site, when the soil moisture was thought to be quite low, resulted in few of the burned plants sprouting. When prescribed burns were conducted at North site, which typically exhibited a late summer and early fall rain pattern, a somewhat higher percentage of plants sprouted.

Bitterbrush stand establishment following fire demonstrates interesting trends (table 2). At one end of the spectrum in the spring burn sites that typically exhibited a low rainfall pattern following the fire, only 50 seedlings per acre (124 per ha) were observed regardless of location. In contrast to this the fall burn sites exhibit twice the density of seedlings. The explanation for this latter observation, however, is complex because the South burned more completely than the North. The observations on the seedling establishment on the pile and burn treatment offer somewhat of a lead in that hot burns greatly reduce the vegetative competition from pinegrass for at least 3 years following the fire. This effect is thought to be a significant factor to bitterbrush seedling establishment. Regardless of the true ecological processes responsible for these results, hot burns in small areas within similar habitats appear to provide for bitterbrush seedling establishment.

The response of the bitterbrush populations at the South sites exhibiting vigorous sprouting pose an interesting question: could there be a difference in this population due to the history of natural fire occurrence?

Interestingly, many of the plants that sprouted exhibited lignotubers. Daubenmire (1974) describes this as a structure that gives rise to many adventitious buds and is usually located at the soil interface on the main stem of a woody plant. Lignotubers have been commonly observed on many of the shrub species found in the California chaparral. The structure is commonly associated with woody plants in communities typically exposed to frequent fires.

This indicates that the population I have been observing could have resulted from a long period of selection for sprouting abilities by a history of high fire frequency. Such actions could have led to the development of a sprouting ecotype. This may have been a feasible function as demonstrated by Blaisdell's (1953) report of high sprouting rate following a reburn treatment.

In addition, Blaisdell and Mueggler (1956) reported that sprouts appeared to be derived in two ways: "from an existing mass of dormant buds wholly or partly encircling the stem at ground level, or from a callus of meristematic tissue formed beneath the bark after treatment and encircling the stem." The former description of meristematic tissue appears to fit that given by Daubenmire (1974) characterizing a lignotuber. Therefore, Blaisdell's (1953) and Blaisdell and Mueggler's reports (1956), along with my observations appear to establish the basis for further investigations into the occurrence or development of genetically controlled sprouting ability in this shrub species.

In conclusion, fire could be a functional tool in managing antelope bitterbrush in habitats similar to those in which these observations were made. More specifically, prescribed fire used in early spring at the time of high soil moisture should ensure the possibility of many of the plants of this species giving rise to vegetative sprouts resulting in vigorous growth. Hot fires, especially during periods of low soil moisture, can lead to seedling establishment if a seed source is available. Therefore many aspects of fire can play a vital role in the management of this vital wildlife browse shrub. Much more specific information is needed, however, to accurately prescribe the conditions for burning and fully understand the functions of fire in accomplishing the goals of managing this vital shrub resource.

PUBLICATIONS CITED

Barney, R. J. Fire management: a definition. J. For. 73: 498-519; 1975.

Billings, W. D. The environmental complex in relation to plant growth and distribution. Q. Rev. Biol. 27: 251-265; 1952.

Blaisdell, J. P. Ecological effects of planned burning of sagebrush-grass range on the Upper Snake River Plains. Tech. Bull. 1975. Washington, DC: U.S. Department of Agriculture, Forest Service; 1953. 34 p.

Blaisdell, J. P.; Mueggler, W. F. Sprouting of bitterbrush (Purshia tridentata) following burning or top removal. Ecology. 37: 365-370; 1956.

Clark, R. G. Seasonal response of bitterbrush to burning and clipping in Eastern Oregon. Corvallis, OR: Oregon State University; 1979. 109 p. M.S. thesis.

Daubenmire, R. F. Plants and environment: a textbook of autecology. 3d ed. New York: John Wiley & Sons. 422 p.

Driver, C. H.; Winston, V. A.; Goehle, H. F. The fire ecology of bitterbrush - a proposed hypothesis. In: Proceedings, sixth conference on fire and forest meteorology. Washington, DC: Society of American Foresters; 1980: 204-208.

Hormay, A. L. Bitterbrush in California. Res. Note 34. Berkeley, CA: U.S. Department of Agriculture, California Forest and Range Experiment Station; 1943. 13 p.

Nord, E. C. Autecology of bitterbrush in California. Ecol. Monogr. 35: 307-334; 1965.

Wright, H. A.; Neuenschwander, L. F.; Britton, C. M. The role and use of fire in sagebrush-grass and pinyon-juniper plant communities: a state-of-the-art review. Gen. Tech. Rep. INT-58. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1979. 48 p.

RESPONSE OF ANTELOPE BITTERBRUSH TO BURNING AND SPRAYING IN SOUTHEASTERN IDAHO[1]

Robert B. Murray[2]

ABSTRACT

Long-term response (1936-1979) of Purshia tridentata is reported for an August 1936 prescribed burn and an accidental 2,4-D spray in 1961. On unburned plots bitterbrush yields in 1966 were more than twice those on burned plots. Spraying with 2,4-D in 1961 resulted in relatively large increases in bitterbrush yields in 1966 and declines in big sagebrush studies on spring and late summer burning are included.

INTRODUCTION

Antelope bitterbrush (Purshia tridentata Pursh. DC) is a highly preferred browse species for big game on winter ranges in the Western United States (Julander and Robinette 1950; Robinette and others 1952; Hoskins and Dalke 1955; and McConnell and Dalke 1960). However, on many winter ranges overgrazing, decadence, or encroachment by big sagebrush (Artemisia tridentata Nutt.) has severely reduced the availability of bitterbrush for big game. Prescribed burning and spraying with herbicides are two techniques commonly used by land managers to renovate sagebrush-bitterbrush stands to make them more productive. Such improvement practices as well as some wildfires have not always been beneficial for bitterbrush.

This paper reports the long-term results from burning and the effects of spraying with 2,4-D on the response of bitterbrush and associated shrubs (mountain big sagebrush A. tridentata ssp. vaseyana; green rabbitbrush, Chrysothamnus viscidiflorus [Hook] Nutt.; and gray horsebrush, Tetradymia canescens DC) in southeastern Idaho. Recent work on spring versus late summer burning on bitterbrush is also reported.

REVIEW OF LITERATURE

Work done in California (Hormay 1943) and in the Western Great Basin (Billings 1952) showed that the rarity of sprouting of bitterbrush following burning in these areas would permanently eradicate the species. Also in California, Countryman and Cornelius (1957) found bitterbrush was completely absent from a burned area 6 years after wildfire, while on an adjacent unburned area bitterbrush constituted 91 percent of the vegetal cover. Nord (1965) observed that bitterbrush sprouting was frequent to abundant on 5 of 13 burns he examined in California; only where appreciable sprouting occurred was recovery successful. He concluded that the recovery process was slow, often requiring 30 or more years to be complete.

In southeastern Idaho Blaisdell (1953) reported that bitterbrush production was less on burned areas compared to unburned areas 15 years following the Fremont County prescribed burn and similarly 12 years following the Clark County prescribed burn.

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[1] Paper presented at the Bitterbrush and Cliffrose Symposium, Salt Lake City, Utah, April 13-15, 1982.

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The areas were burned in September 1932 and August 1936, respectively. In the year following the Fremont County fire 49, 43, and 19 percent of the bitterbrush plants had sprouted in areas of light, moderate, and heavy intensity burning, respectively. However, the fire reduced the number of the original live plants, which resulted in lower production.

In central Oregon Driscoll (1963) reported that bitterbrush sprouting varied from 1 to 80 percent of the plants following summer wildfires. He concluded that environmental factors were more important in regulating sprouting success than were burn intensities. Production was not reported, nor has productivity been followed over time for these burns.

If done at the right time, spraying with herbicides is less detrimental to bitterbrush than burning. Blaisdell and Mueggler (1956) examined a number of spray areas in southeastern Idaho and found bitterbrush was unharmed on four sites and only slightly damaged on a fifth. In a controlled study, Mueggler and Blaisdell (1958) found bitterbrush was severely injured by burning, but was favored by spraying with 2,4-D. Spraying with 2,4-D before bitterbrush flowers resulted in less crown mortality and effective reductions in big sagebrush (Hyder and Sneva 1962). Although spraying appears to be more beneficial to bitterbrush than burning, the accompanying reduction forbs may not be desirable.

STUDY AREA AND METHODS

Our study was conducted on the Upper Snake River Plains at the U.S. Sheep Experiment Station approximately 11 mi (18 km) northeast of Dubois, Idaho, in Clark County. Blaisdell (1953) described the general vegetal character prior to burning as a dense stand of big sagebrush 2 to 4 ft (0.6 to 1.2 m) high with a fairly continuous stand of perennial grasses. The perennial graminoids were thickspike wheatgrass (Agropyron dasystachyum [Hook] Scribn.), bluebunch wheatgrass (A. spicatum [Pursh] Scribn. & Smith), plains reedgrass (Calamagrostis montanensis Scribn.), bluegrasses (Poa L. spp.) and sedges (Carex L. spp.). He indicated the vegetation composition was roughly 35 percent perennial grasses, 5 percent perennial forbs, 5 percent annual forbs, 40 percent sagebrush, 15 percent perennial forbs, 5 percent annual forbs, 40 percent sagebrush, and 15 percent rabbitbrush, horsebrush, and other shrubs. Bitterbrush was a small component of the total.

Topography is typical of the Upper Snake River Plains with lava outcrops interspersed with deeper soil swales. Soils are derived from basalt and aeolian sources. Textures in the soil surface are sand to silt loams. Long-term precipitation records at the headquarters show that annual precipitation averages 11.6 inches (295 mm) per year, with extreme variability from year to year. May and June receive the most precipitation on the average.

In 1936, 400 plots 100 ft^2 (9.3 m^2) were systematically established within 1 mi^2 (2.6 km^2) (T11N, R37E, Sec. 15) area and were measured using the weight estimate technique (Pechanec and Pickford 1937). Current growth of shrubs was measured. In August 1936, the area was burned. After burning, each plot was rated or burn intensity using the following classification: (1) heavy burn - trunk or main tem consumed by fire; (2) moderate burn - larger branches of sagebrush remaining, ut smaller branches and twigs consumed; (3) light burn - smaller branches and twigs nburned, on leaves consumed by fire; and (4) unburned - no evidence of fire either n the understory or sagebrush crowns.

The subsequent years (1937, 1939, 1948, 1966, and 1979) most plots were emeasured using the same weight estimate technique. Some plots were not measured because of sampling reduction, lost plots, or reburned plots. The actual number measured in the above years were 400, 400, 373, 297, and 387, respectively.

A wildfire in 1947 burned over a portion of the original area. Therefore, 27 plots were not measured in 1948. An adjacent area was sprayed with 2,4-D in 1961 and some of the herbicide drifted over the burn area affecting 150 plots. These plots were identified prior to the 1966 sampling. In 1966 only three-fourths of the total plots were measured in an effort to reduce the sampling load. The difference in the numbers of plots sampled has a bearing on some of the discussions that follow.

Only 40 plots contained bitterbrush in 1936. These were associated with lava outcrops and swales, and after burning were related to burn intensity. Since there were so few plots in each classification a rigorous statistical analysis was not possible. Therefore, the approach taken in this paper has been to make inference based on trends.

Blaisdell (1953) reported the vegetation production response through 1948, but did not make a separate statistical analysis for bitterbrush because he believed the data were inadequate. Harniss and Murray (1973) evaluated the results of the same burn through 1966 and concentrated on the principal shrubs, but they did not consider the effects of the 1961 spraying. In this paper the effects of burning and spraying on bitterbrush are reexamined for the Clark County burn during the 43-year period from 1936 through 1979.

RESULTS AND DISCUSSION

The results in the following sections are based on all plots that contained bitterbrush in any one of the 6 measurement years. These plots are analyzed in terms of burn intensities (described in the methods section), subtypes (plots on lava outcrops or on swale areas), and treatments (those burned in 1936, those burned in 1936 and sprayed in 1961). For each consideration the data represent averages for the respective groups.

Effect of Burn Intensities

Yields of bitterbrush, big sagebrush, rabbitbrush, and horsebrush and the percentage of these yields to the unburned yields in 1936 are given in table 1.

Prior to burning in 1936, bitterbrush yields averaged 13.7 lbs/acre (15.4 kg/ha) and reached a peak in 1966 regardless of burn intensity. The effects of burn intensity continued to persist as evidenced by smaller percentage yield increases with more intense fires. In 1966, the average bitterbrush yield of 106.3 lbs/acre (119.1 kg/ha) on unburned plots was more than twice the average yield of burned plots at 52.4 lbs/acre (58.7 kg/ha). Bitterbrush yields in 1979 declined considerably from 1966 levels due to a severe outbreak of tent caterpillar (Malacosoma californicum) from 1977 to 1979.

Big sagebrush was severely damaged by burning; until 1966 yields on the burned plots were considerably lower than those on unburned plots. In 1966 the average yields of big sagebrush on these bitterbrush plots were higher than those in 1936 even though 48 percent of the plots had been sprayed with 2,4-D in 1961. Rabbitbrush and horsebrush yields were reduced the year following burning, but increased through 1948. A positive relationship existed in both species between yield and burn intensities. Rabbitbrush yield declined in 1966 and 1979, while horsebrush yields increased in 1966 than declined in 1979.

Table 1.--Mean yields in pounds per acre and percentage of 1936 yield for bitterbrush, big sagebrush, rabbitbrush, and horsebrush in relation to burn intensity and year. U.S. Sheep Experiment Station, Dubois, Idaho.

Species	Year	Mean yield	Percent of 1936	Mean yield	Percent of 1936	Mean yield	Percent of 1936	Mean yield	Percent of 1936
Bitterbrush	1936	9.5	0	17.0	0	13.2	0	15.3	0
	1937	20.3	114	0.3	-98	0.0	-100	0.9	-94
	1939	51.6	445	12.3	-27	8.0	-39	2.2	-86
	1948	31.9	237	20.2	19	12.8	-3	10.5	-31
	1966	106.3	1024	64.5	281	44.3	236	48.4	217
	1979	27.2	188	12.4	-27	17.9	36	12.9	-15
Big sagebrush	1936	166.9	0	128.6	0	140.0	0	148.1	0
	1937	382.3	129	15.2	-88	0.2	-100	0.1	-100
	1939	353.1	112	16.6	-87	1.2	-99	2.3	-98
	1948	399.5	139	46.9	-63	89.1	-36	10.5	-46
	1966	165.1	-1	197.3	53	187.8	34	156.3	6
	1979	171.3	3	163.3	27	164.6	18	176.3	19
Rabbitbrush	1936	32.5	0	49.7	0	22.5	0	16.4	0
	1937	18.4	-43	24.0	-52	22.2	-1	13.5	-18
	1939	22.7	-30	60.8	22	62.0	176	59.7	264
	1948	22.2	-32	69.8	40	53.9	140	67.6	312
	1966	11.9	-63	11.0	-78	15.4	-31	4.5	-73
	1979	11.0	-66	12.6	-75	20.3	-10	6.7	-59
Horsebrush	1936	8.6	0	19.7	0	17.3	0	28.0	0
	1937	7.5	-12	7.8	-61	8.8	-49	15.1	-46
	1939	12.3	44	18.4	-7	33.4	93	64.2	129
	1948	5.7	-33	36.0	83	50.9	194	82.6	195
	1966	10.3	20	64.4	227	24.0	39	28.6	2
	1979	6.1	-29	18.3	-7	14.5	-16	19.0	-32
Number of plots by burn intensity:		31		21		36		58	

In 1936 bitterbrush was present in 40 of the original 400 plots (10 percent) and in 103 of the 297 plots (35 percent) sampled in 1966 (table 2). Of the 146 plots containing bitterbrush in 1 of the 6 years sampled, 27 percent contained bitterbrush in 1936 and 71 percent in 1966. The occurrence of bitterbrush in plots in 1936 and 1977 increased from 7 to 26 on unburned plots (271 percent) and from 33 to 77 on burned plots (133 percent).

Bitterbrush was present in 2 of the 33 plots the year following burning. By 1939 bitterbrush had made substantial yield increases and was present in 4 additional nonburned plots. In contrast, yields were well below 1936 levels in the burned areas (table 1), and occurred in only 12 plots. Through 1966--30 years after burning--bitterbrush yields were lower in plots that were burned at higher intensities.

Blaisdell (1953) reported that bitterbrush sprouting was reduced with higher burn intensities. The results from the present study suggest that burn intensity was not the only important factor in regulating bitterbrush recovery. It is likely that bitterbrush became established from seed in the nonburned areas and from sprouting nd seed in the burn areas (table 2). After 1939 any increases in bitterbrush were probably due to establishment from seed. Of the original 33 burned plots, only 10 ontained bitterbrush in 1939, which suggests that these are plots in which itterbrush sprouted. The others became established from seed.

Table 2.--Number of plots containing bitterbrush by burn intensity and year. U.S. Sheep Experiment Station, Dubois, Idaho.

Year	Unburned	Light	Moderate	Heavy	Total
1936	7	6	10	17	40
1937	5	1	0	1	7
1939	11	4	4	4	23
1948	17	4	7	14	42
1966	26	15	28	34	103
1979	18	15	21	36	90

Large increases in grass and forb yields in the burned areas may have influenced the establishment of bitterbrush more than the direct impact of the fire itself. Unfortunately, the unusually low numbers of plots containing bitterbrush at the time of the burn did not permit an assessment of the direct impact. However, burning appeared to have a very long-lasting effect on bitterbrush recovery. This possibly was due to the competitive effects of the other vegetation.

Between 1939 and 1948, during the period when grass and forb yields on the burned areas were greatest, only 13 new bitterbrush plots were established. Much of the increase in yield was due to the rhizomatous, thickspike wheatgrass, which is a vigorous competitor. The most establishment came between 1948 and 1966 as grass and forb yields declined and big sagebrush yields increased. During this period 52 plots became established in the burn areas (208 percent) compared to 9 in the nonburned areas (53 percent). These figures could lead the reader to believe burning enhanced establishment, but they are misleading. When the establishment percentages are calculated on the basis of the total nonburned and burned plots, then 50 percent of the nonburned plots contained bitterbrush compared to 31 percent in burned areas.

In 1979 there was a reduction in the number of plots containing bitterbrush due to a severe infestation of tent caterpillar. However, there is evidence to suggest establishment was continuing between 1966 and 1979. Of the 103 plots with bitterbrush in 1966, 46 did not contain bitterbrush in 1979; and 33 plots devoid of bitterbrush in 1966 contained bitterbrush in 1979. If one could assume no loss from tent caterpillar while incorporating the gain from newly colonized plots, nearly 45 percent of the plots would have contained bitterbrush in 1979.

Effect of Burning and Spraying

Yields of the four species and percentages of 1936 yields are shown in table 3 for plots that were burned in 1936, and for plots that were both burned in 1936 and sprayed with 2,4-D in 1961.

Bitterbrush yields in 1966 were 620 percent greater than 1936 yields on sprayed plots compared to 241 percent greater yield for nonsprayed plots. On sprayed plots

Table 3.--Mean yields in pounds per acre and percentage of 1936 yield for bitterbrush, big sagebrush, rabbitbrush, and horsebrush in relation to burning only and burning plus spraying with 2,4-D. U.S. Sheep Experiment Station, Dubois, Idaho.

		Bitterbrush		Big sagebrush		Rabbitbrush		Horsebrush	
Treatment	Year	Mean yield	Percent of 1936	Mean yield	Percent of 1936	Mean yield	Percent of 1936	Mean yield	Percent of 1936
Burned 1936	1936	13.2	0	141.3	0	37.4	0	20.0	0
	1937	6.9	-48	78.1	-45	26.9	-28	10.5	-47
	1939	16.3	24	77.0	-46	72.2	93	33.9	70
	1948	16.5	25	134.0	-5	77.5	107	48.5	143
	1966	45.0	241	243.7	72	16.5	-56	30.3	52
	1979	21.1	59	131.1	-7	15.2	-59	15.4	-23
Burned 1936+	1936	10.3	0	152.3	0	11.4	0	21.8	0
Sprayed 1961	1937	1.5	-85	97.4	-36	8.3	-27	12.2	-44
	1939	8.4	-18	87.3	-43	24.6	116	47.7	119
	1948	23.2	126	174.5	15	38.1	234	61.1	181
	1966	73.9	620	84.1	-45	1.7	-85	28.4	30
	1979	7.0	-32	219.1	44	4.6	-59	15.6	-28

Table 4.--Number of plots containing bitterbrush by treatment and year. U.S. Sheep Experiment Station, Dubois, Idaho*

Year	Burned only	Burned and sprayed
1936	21	15
1937	2	3
1939	10	11
1948	25	17
1966	43	53
1979	49	35

*Does not include plots reburned in 1947

big sagebrush yields declined from 174.5 to 84.1 lbs/acre (195.6 to 943. kg/ha) (107 percent) compared to an increase from 134.0 to 243.7 lbs/acre (150.2 to 273.1 kg/ha) (82 percent) on nonsprayed plots between 1948 and 1966. There were greater reductions in rabbitbrush and horsebrush yields between 1948 and 1966 on sprayed plots than on nonsprayed plots. In addition, the occurrence of bitterbrush in sprayed plots increased from 17 to 53 (212 percent) compared to an increase from 25 to 43 (72 percent) on nonsprayed plots over this same time period (table 4).

Spraying in 1961 resulted in increases in yield by bitterbrush and decreases by other shrub species. Most of the yield increases were due to reduced competition from the other shrubs. Spraying also permitted greater establishment compared to the nonsprayed areas. While the occurrence of bitterbrush on sprayed plots increased 212 percent and 72 percent in nonsprayed plots between 1948 and 1966, it is noteworthy that bitterbrush disappeared from 39 plots in sprayed areas between 1948 and 1966 compared to 19 in nonsprayed areas. Although it is not possible to determine exactly when the plots became established, the yields in many plots in 1966 were quite low, suggesting that establishment was recent and probably occurring after spraying.

One might expect that spraying and burning would have a similar effect on establishment due to increased grass production. An explanation for the greater establishment of bitterbrush on the sprayed areas is elusive. One explanation is that establishment may have proceeded immediately following spraying and before competition from grasses became severe.

Effect of Site

Mean yields and percentages of the 1936 yields for the four shrub species are given in table 5.

Bitterbrush yields were greater in all years on plots associated with lava outcrops compared to plots in swales. The increase in numbers of plots containing bitterbrush from 1936 to 1966 was 137 percent in lava outcrop sites and 200 percent in swales (table 6). However, when viewed relative to the total number of plots, bitterbrush occurred in 56 percent of the plots in the rocky sites compared to 21 percent of the plots located in the swales. Undoubtedly, postburn responses of other vegetation influenced the establishment of bitterbrush through 1948. Thereafter, a greater increase occurred proportionately in the swale areas. Part of the increase was due to the effect of spraying.

Table 5.--Mean yields in pounds per acre and percentage of 1936 yield for bitterbrush, big sagebrush, rabbitbrush, and horsebrush in relation to lava outcrops and swale sites. U.S. Sheep Experiment Station, Dubois, Idaho.

		Bitterbrush		Big sagebrush		Rabbitbrush		Horsebrush	
Subtype	Year	Mean yield	Percent of 1936	Mean yield	Percent of 1936	Mean yield	Percent of 1936	Mean yield	Percent of 1936
Lava outcrops	1936	20.3	0	153.3	0	31.9	0	14.9	
	1937	8.0	-60	80.4	-48	22.9	-28	8.2	-4
	1939	27.7	37	79.8	-48	64.0	100	29.2	9
	1948	28.9	43	155.5	1	50.1	57	36.5	14
	1966	98.3	385	200.8	31	11.3	-65	29.1	3
	1979	28.7	42	172.0	12	16.6	-48	10.3	-3
Swales	1936	7.0	0	141.0	0	20.0	0	25.4	
	1937	1.2	-82	86.6	-39	13.2	-34	13.7	-4
	1939	2.0	-59	77.4	-45	40.5	103	49.4	9
	1948	8.0	15	135.1	-4	60.0	200	67.9	16
	1966	23.6	240	141.1	0	7.8	-61	37.8	4
	1979	4.9	-29	169.0	20	6.7	-67	20.1	-2

Table 6.--Number of plots and percentage of 1936 numbers in relation to lava outcrop and swale sites. U.S. Sheep Experiment Station, Dubois, Idaho.

	Lava outcrop		Swales	
Year	Number	Percent	Number	Percent
1936	27	100	13	100
1937	5	19	2	15
1939	17	63	6	46
1948	28	103	14	108
1966	64	237	39	300
1979	51	189	39	300

In the swales areas 51 percent of the plots contained bitterbrush for the first time in 1966 compared to 21 percent in the rocky areas. All plots were sprayed suggesting spraying may have had an important influence on the establishment of bitterbrush.

Prior to burning in 1936, bitterbrush occurred in more plots on rocky sites (27) than in plots in swales (13) (table 6). In every year thereafter bitterbrush continued to be more prevalent on the rocky sites. Today, observations across the entire U.S. Sheep Experiment Station indicate that bitterbrush is actually more prevalent and productive in the swale areas compared to the rocky sites. The difference between data from 1936 and the present observations may be due to the extended drought preceding the burn.

An examination of all plot records for 1936 revealed that grasses, forbs, and shrubs were greater in the swales than on rocky sites. The vegetation production averaged 546.0 lbs/acre (612 kg/ha) in the swales and 446.1 lbs/acre (500 kg/ha) on the lava outcrop plots. During the period of below normal precipitation, competition for soil moisture was probably more severe in the swale areas due to a greater demand from a more luxuriant vegetation. As demand exceeded availability certain species were stressed beyond their tolerance and were reduced. On the rocky sites, even under reduced soil moisture conditions, more water may have been available for the shrubby component resulting in less loss proportionately. Total biomass was still greater in the swale areas compared to the rocky areas in 1936 in spite of the possible larger reductions in yields in the swale areas.

Sites with a heavier understory fuel load preheat the overstory more rapidly and effectively. This and heavier overstory fuel load give rise to fire of greater severity. Consequently, in swale areas where fuels were heavier, it is expected that the increased burn intensity lowered sprouting of bitterbrush and resulted in lower yields.

Big sagebrush and rabbitbrush yields were more erratic after burning with respect to yearly response and site. Horsebrush, on the other hand, was more productive in the swale areas over the 43 years.

Spring Versus Late Summer Burning

The original plots were measured in 1979 to terminate the 1936 burn study and to provide initial data for a comparison of spring versus late summer burning. In late August and early September of 1979 two burns of 160 acres (65 ha) in size were conducted. In mid-April 1981 another quarter section was burned. The yields of the four shrubs are given in table 7 by treatment and year.

Bitterbrush yields increased from 23.6 to 91.0 lbs/acre (26.4 to 102.0 kg/ha) from 1979 to 1980 on the area burned in the spring. Plots that were not burned in both the spring and late summer burned areas, showed increases in bitterbrush yields from 33.1 to 158.2 lbs/acre (37.2 to 177.3 kg/ha) from 1979 to 1981. This indicates that bitterbrush was likely recovering from tent caterpillar damage and that environmental conditions were favorable.

As expected, burning in the spring or late summer caused reductions in yields of all shrubs. Although the postburn yields of bitterbrush were less in the spring burn area (12 percent) compared to the fall burned area (29 percent), studies conducted at

Table 7.--Mean yields in pounds per acre and percentage of yields for bitterbrush, big sagebrush, rabbitbrush, and horsebrush in relation to spring and fall burning. U.S. Sheep Experiment Station, Dubois, Idaho.

		Bitterbrush		Big sagebrush		Rabbitbrush		Horsebrush	
	Year	Mean yield	Percent	Mean yield	Percent	Mean yield	Percent	Mean yield	Percent
Nonburned	1979	33.2	100	149.1	100	18.8	100	15.0	100
	1980	90.8	274	149.8	100	20.9	111	21.0	140
	1981	158.2	477	122.6	82	13.5	72	35.2	235
Spring[1]	1979	13.6	100	271.0	100	16.0	100	18.2	100
	1980	91.0	100	205.0	100	2.7	100	18.5	100
	1981	11.2	12	28.0	14	0.7	27	10.4	57
Fall[2]	1979	9.4	100	217.5	100	7.4	100	10.6	100
	1980	2.7	29	17.6	8	3.7	49	7.3	69
	1981	2.5	27	9.8	5	5.7	77	11.2	105

[1] Percent based on 1980

[2] Percent based on 1979

the Sheep Station suggest that sprouting following spring burning will be greater than late summer burning (Murray[3]) and will ultimately give rise to greater yields.

Blaisdell (1953) reported that 43 percent of the bitterbrush plants sprouted when burned in September at a moderate intensity. However, when burned in the spring (mid-April) at the same intensity, bitterbrush sprouted at an 80 percent rate (Murray[3]). Even though conditions of the vegetation and weather conditions produce burns of similar intensity, factors such as soil moisture greatly influence sprouting. When soils are moist at the time of the burn there appears to be less damage at the root collar where sprouting occurs.

Even when sprouting occurs plants may die depending upon the severity of the winter. If young sprouts are protected by ample snow during the winter many will survive the subfreezing weather. However, if they are exposed, most will perish. In addition, if young sprouts are grazed during the first year, overwinter mortality will increase (Murray[3]).

MANAGEMENT RECOMMENDATIONS

Evidence from this and other studies conducted in the sagebrush-grass region of the Western United States suggests that burning in mixed sagebrush-grass stands does not enhance antelope bitterbrush yields. Recovery of bitterbrush from fire required many years even though individual sprouted plants may achieve greater yields in a relatively short time. The principal problems arise from the large numbers of plants that are killed immediately or have low sprouting success, or where competition from other species reduces establishment of new plants.

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[3] Murray, Robert B. Sprouting of bitterbrush in response to spring burning. (Manuscript in preparation.)

If fire is being contemplated to maximize yields of bitterbrush, then burning should be conducted early in the spring or late in the fall. To minimize damage to grasses and forbs burns should be done while they are dormant in the spring or before regrowth occurs in the fall. High soil moisture at the time of the burn appears to enhance sprouting of bitterbrush. Therefore, it is important to establish periods when these conditions prevail in each locality in which prescription burning is to be used.

On the Upper Snake River Plains our experience indicates that burns can be conducted successfully during mid- to late April. The actual period may vary depending upon winter conditions, especially in the amount of snow. During this period snow has recently disappeared, soil moisture is high, daytime temperatures often rise to 60 to 70° F (15.6 to 21.1° C) drying the previous year's litter, moisture in sagebrush is less than 100 percent (dry weight basis), relative humidities often fall below 30 percent, and the height of new grass growth is less than 2 inches (5 cm). In some years inclement weather does not permit burning, and usually the time when burns can be conducted is limited to only a few days.

The long-term effects of burning on bitterbrush recovery are an important consideration for land managers whose primary goal is to rejuvenate bitterbrush stands. Burns should be conducted under environmental conditions that produce low-intensity burns to enhance sprouting. However, even with increased sprouting from spring or late fall burning, overwinter mortality and damage from either livestock or big game grazing on new sprouts lowers overall sprout survival. Therefore, to ensure maximum regeneration and yields in a relatively short time consideration should be given to the desirability for planting or seeding bitterbrush immediately following burning.

When burns are prescribed to improve forage conditions for sheep, enhancement of bitterbrush is usually not an objective even though it is highly palatable to sheep. Here the goal is to increase forage and reduce the amount of defoliated shrub branches. The shrub skeletons left following spraying or burns of low intensity are undesirable, because the skeletons pull wool. As a result, sheep tend to avoid such areas. Consequently, burning should be done when conditions promote more intense burns.

PUBLICATONS CITED

Billings, W. D. The environmental complex in relation to plant growth and distribution. Q. Rev. Biol. 27(3): 251-265; 1952.

Blaisdell, James P. Ecological effects of planned burning of sagebrush-grass range on the Upper Snake River Plain. Tech. Bull. 1075. Washington, DC: U.S. Department of Agriculture; 1952. 39 p.

Blaisdell, James P.; Mueggler, Walter F. Effect of 2,4-D on forbs and shrubs associated with big sagebrush. J. Range Manage. 9(1): 38-40; 1956.

Countryman, Clive M.; Cornelius, Donald R. Some effects of fire on a perennial range type. J. Range Manage. 10(1): 39-41; 1957.

Driscoll, Richard S. Sprouting bitterbrush in central Oregon. Ecology 44(4): 820-821; 1963.

Harniss, Roy O.; Murray, Robert B. 30 years of vegetal change following burning of sagebrush-grass range. J. Range Manage. 26(5): 322-325; 1973.

Hormay, August I. Bitterbrush in California. Res. Note 34. Berkeley, CA: U.S. Department of Agriculture, Forest Service, California Forest and Range Experiment Station; 1943. 13 p.

Hoskins, Leonard W.; Dalke, Paul D. Winter browse on the Pocatello big game range in southeastern Idaho. J. Wildl. Manage. 19(2): 215-225; 1955.

Hyder, D. N.; Sneva, Forrest A. Selective control of big sagebrush associated with bitterbrush. J. Range Manage. 15(4): 211-215; 1962.

Julander, Odell; Robinette, W. Leslie. Deer and cattle range relationships on Oak Creek range in Utah. J. For. 48(6): 410-415; 1950.

McConnell, Burt R.; Dalke, Paul D. The Cassia deer herd of southern Idaho. J. Wildl. Manage. 24(3): 265-271; 1960.

Mueggler, Walter F.; Blaisdell, James P. Effects on associated species of burning, rotobeating, spraying, and railing sagebrush. J. Range Manage. 11(2): 61-66; 1958.

Nord, Eamor C. Autecology of bitterbrush in California. Ecol. Monogr. 35(3): 307-334; 1965.

Pechanec, J. F.; Pickford, G. D. A weight estimate method for determination of range on pasture productions. J. Am. Soc. Agron. 29: 894-094; 1937.

Pechanec, J. F.; Pickford, G. D.; Stewart, George. Effects of the 1934 drought on native vegetation of the Upper Snake River Plains, Idaho. Ecology. 18: 490-505; 1937.

Robinette, W. Leslie; Julander, Odell; Gashwiler, Jay S.; Smith, Justin G. Winter mortality of mule deer in Utah in relation to range condition. J. Wildl. Manage. 16(3): 289-291; 1952.

BITTERBRUSH MANAGEMENT ON THE BOISE WILDLIFE MANAGEMENT AREA[1]

Gerald C. Scholten[2]

ABSTRACT

By using cattle and sheep in a managed grazing system, 16,500 acres of mule deer winter range have been improved. Grazing is used to increase bitterbrush vigor, stimulate bitterbrush leader growth, and improve forage composition. Artificial revegetation by seed and seedlings is used to enhance bitterbrush population in selected areas.

INTRODUCTION

The Boise River Wildlife Management Area is managed under a cooperative management plan by the Idaho Department of Fish and Game, Idaho Department of Lands, USDA Forest Service, USDI Bureau of Land Management, U.S. Army Corps of Engineers, and Highland Livestock and Land Company. Technical assistance is supplied by the Soil Conservation Service and the Agriculture Research Service-Northwest Watershed Research Center. The Idaho Department of Fish and Game is responsible for implementing the management program with approval from the cooperating agencies and private landowner.

The current management objectives are: (1) improve mule deer winter range, (2) increase upland game production, (3) provide public hunting, and (4) provide for wildlife appreciation. Proper bitterbrush management is essential to achieve the first management objective.

DESCRIPTION OF AREA

The 16,500 acre (6600 ha) Boise Front management segment is located 3 miles (4.8 km) east of Boise, along the Lucky Peak Reservoir. The area is steep with slopes to 60 percent and elevations range from 2,800 ft (850 m) to 5,900 ft (1800 m). The area has numerous canyons that drain into the Boise River. It is intermingled with heavy clay, loams, and sandy granitic soils. Precipitation ranges from 12 inches (30.5 cm) at lower elevations to 26 inches (66.0 cm) above 5,000 ft (1520 m). Most of this is received during the late fall to early spring. Temperatures range from -23° to 108° F (-30° to 43° C). Bitterbrush (*Purshia tridentata*), big sagebrush (*Artemisia tridentata*), gray rabbitbrush (*Chrysothamnus nauseosus*), and willow (Salix spp.) are the most common browse species. Bluebunch wheatgrass (*Agropyron spicatum*), bottlebrush squirreltail (*Sitanion hystrix*), cheatgrass (*Bromus tectorum*), and Sandberg bluegrass (*Poa secunda*) are the most common grasses. Key forbs consist of arrowleaf balsamroot (*Balsamorhiza sagittata*), phlox (*Phlox* spp.), and hawksbeard (*Crepis spp.*)

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[1] Paper presented at the Bitterbrush and Cliffrose Symposium, Salt Lake City, Utah, April 13-15, 1982.

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Cattle and sheep graze the area in the spring and early summer. Some sheep use occurs again in the fall. During the winter, 800 to 4,600 mule deer, and occasionally elk, use the area. The wide difference in deer numbers using the area was found to be related to temperature and water content of snow above the 5,000 ft (1520 m) elevation. A multiple regression equation has been developed that shows this relationship:

$$Y = 2039 + 200_{X1} - 524_{X2} - 3_{X3}$$

where Y is deer animal unit months, X1 is the mean January temperature in C°, X2 is the mean February temperature in °C, and X3 is the snow water content in mm of the nearest snow course marker on January 1. The multiple correlation coefficient is r + 0.91 and the standard error of estimate is 303 (Johnson and others 1980).

MULE DEER FOOD HABITS

Information on plant preference by mule deer and season of use is needed in bitterbrush management and overall management of the winter range. To get this information, rumen samples were collected from deer hit by cars on State Highway 21, which runs through the middle of the management area.

Rumen samples from 45 road-killed deer during January to April from 1971 to 1975 were analyzed by the Idaho Department of Fish and Game laboratory in Boise. The results showed that peak use, 30 percent, occurred during January, when snows are usually the deepest. This is based on air dry weights. Sagebrush use is also high, 29 percent, during periods of deep snow. Use of grasses increases as spring green up occurs and shrub use declines. Sage and grasses are considerably more abundant than bitterbrush, which indicates the importance of bitterbrush in maintaining the wintering mule deer population.

CATTLE MANAGEMENT

In 1970 a rest season grazing system (Lacey and VanPoolen 1979) was implemented to improve mule deer winter range and watershed values. The program had two goals: (1) to improve perennial grasses, and (2) to improve bitterbrush. The objectives for perennial grasses were to restore vigor, increase their percentage composition, provid additional ground litter, increase soil moisture, and reduce soil temperature. The program objectives for bitterbrush were to provide for maximum hedging to increase vigor and provide more forage, provide the required 2 years of rest for maximum twig growth, and increase bitterbrush density through greater seed production and trampling of seed by livestock.

The system, started in 1970, consisted of eight pastures--four pastures ranged in elevation from 2,800 to 3,600 ft (850 to 1100 m), and four pastures from 3,600 to 5,900 ft (1100 to 1780 m). The treatments consisted of early grazing, grazing after seed ripe, and rest. Only four of the eight pastures were used in a given year. A total of 194 head of cattle were used from April 1, or when range readiness occurred, until November 30. Table 1 shows changes.

Three private landowners included their lands in the program to be managed for mule deer winter range. In return they were allowed to graze on the cooperative agencies' lands. During 1972 one rancher sold his land to the Department of Fish and Game and another dropped out of the program because of ill health. From 1970 to 1974 cattle numbers ranged from 91 to 194 head. Observations show that cattle preferred bitterbrush from mid-May through June and again in September and October.

In 1976 the program was modified to allow 108 head of cattle to graze for 7 months. The cattle had been using an adjacent Forest Service allotment. This change allowed a winter range for mule deer and elk to be partially rested. The pastures and rotation system remained the same. Samples of bitterbrush, using a southwest regional twig diameter-length regression equation, developed by Ferguson and Marsden (1977), showed the overall use was reaching the desired 30 to 40 percent hedging. Observation indicated that we were not utilizing grasses sufficiently in some areas of the pastures, thus creating a "wolf" (tough, rank) plant community.

Table 1.--Changes in grazing seasons and cattle numbers

Years	Grazing season	Maximum cattle numbers
1970-74	April 1 to November 30	194
1975	No grazing	
1976-80	April 1 to October 31	208
1981-82	April 15 to July 31	375

In 1981 the program was again modified to 3.5 months, 375 head allotment beginning April 15 or when range readiness occurred. This was done: (1) to achieve 30 to 40 percent cattle use on bitterbrush in the use pastures, to stimulate leader growth, and to hedge the bitterbrush plant; (2) to utilize grasses and forbs to reduce competition for browse species; (3) to utilize grasses and forbs to prevent "wolf" plant communities from developing; and (4) to insure that the range was maintained in an early or mid-successional stage.

The rotation was changed from a low pasture, high pasture, high pasture, low pasture, to a low pasture, low pasture, high pasture, high pasture system because of a late growing season in the high pastures. The first use pasture would receive heavy use and the three remaining pastures would receive moderate use. A pasture would have heavy use once in 4 years followed by 2 years of rest. Results of 1981 measurements indicated a 22.9 percent use by cattle on bitterbrush, up from 1 to 10 percent under the previous systems. The cattle use, plus the 10 to 60 percent deer use, is expected to keep the bitterbrush plants in good form, class, and vigor (table 2).

Table 2.--Bitterbrush utilization by cattle and mule deer, 1978 to 1982

Year	Percent cattle use	Percent deer use
1978	10.3	38.6
1979	5.5	22.1
1980	1.0	10.4
1981	22.9	60.0

DOMESTIC SHEEP MANAGEMENT

Highland Livestock and Land Company has an exchange of use agreement with the Idaho Department of Fish and Game for 1,200 sheep for 30 days in the spring and 30 days in the fall. In return, the Department manages 875 acres of their private lands for mule deer winter range. The sheep cross the project in alternating strips so that the same areas are not used year after year. The spring sheep use was developed to utliize grasses and forbs, and the fall use is for seed trampling.

ARTIFICIAL REVEGETATION

Artificial revegetation has been accomplished using planting equipment that includes a transplanter for bare-root seedling, a modified corn-vegetable planter for seed, a Hanson browse seeder, rangeland drill, and aerial seeding. All types have worked with varying degrees of success, often dependent on moisture after planting. When scalping was used to reduce competition, the 8 ft (2.5 m) dozer blade provided the best survival rate with 7 percent for seed and 19 to 69 percent for seedlings. A 3 ft (1 m) wide scraper provided a 21.7 percent seedling survival rate while the offset disk provided less than 10 percent. Areas planted with no scalp ranged from 0 to 22 percent seedling survival. Aerial seeding, rangeland drill, and Hanson browse seeders have been used in fire revegetation projects with good success for grasses and shrubs. Estimated costs per acre for the various planting methods are listed in table 3.

Table 3. Cost of planting by various methods

Planting method	Seed/seedling	Pounds or number plants/acre	Cost/acre
Transplanter	Seedling	1,200/acre	$96-$150
Corn-vegetable planter	Seed	2-3 lb/acre	25-50
Hanson browse seeder[1]	Seed	3-4 lb/acre	25-75
Rangeland drill	Seed	12 lb	35-40
Aerial[2]	Seed	12 lb	11

[1] Used with other range treatment, cost of seed only.
[2] Based on 1975 prices.

Insects, rodents, disease, drought, and fire all contribute to losses of bitterbrush. Probably the most severe has been intense wildfires. A wildfire in 1980 left 70 percent of the bitterbrush plants killed with 26 percent resprouting and 4 percent of the burned plants still alive. In 1981 a wildfire killed 91 percent of the bitterbrush plants with only 2 percent resprouting and 7 percent of the burned plants still alive. The Boise Front has a history of wildfire, making fire control and prevention essential. This, coupled with good range management, is essential for enhancement of the mule deer population and watershed protection.

CONCLUSION

A well-managed grazing system can be used to enhance bitterbrush populations through hedging and periodic utilization of the grasses and forbs that reduce competition to the browse species. Artificial revegetation can be used to improve critical mule deer winter ranges. Soil type, moisture condition after planting, methods of planting, and rodent densities can play a key role in the success of the planting. Natural reproduction of bitterbrush has been occurring mainly from rodent caches. Wildfire prevention or control is essential in maintaining the bitterbrush populations. Prescribed burning may be a viable management tool to improve bitterbrus stands.

PUBLICATIONS CITED

Ferguson, Robert B.; Marsden, Michael A. Estimating overwinter bitterbrush utilization from twig diameter-length weight relations. J. Range Manage. 30: 231-236; 1977.

Johnson, Clifton W.; Secrist, Glen M.; Scholten, G. C.; Baum, R. J. Watershed management in action on the Boise Front, Committee on Watershed Management of the Irrigations and Drainage Division of the American Society of Civil Engineers. In: Symposium on watershed management; American Society of Civil Engineers; 1980: 998-1011.

Lacey, John R.; VanPollen, H. Walt. Grazing system identification. J. Range Manage. 32: 38-39; 1979.

ROTOMOWING ANTELOPE BITTERBRUSH--PRELIMINARY REPORT[1]

Robert D. Jones[2]

ABSTRACT

In southeastern Idaho a hand pruning and rotomowing project was undertaken to try to improve the Juniper Mountain deer winter range. Results from the hand pruning trial indicated that the more heavily bitterbrush was pruned the better it responded with increased growth. Based on this, the rotomowing technique was developed. Preliminary results indicated this is a successful tool for this area.

INTRODUCTION

The deteriorating trend of an antelope bitterbrush (Purshia tridentata [Pursh] DC) deer winter range has been a problem facing land managers and big game managers for many years. Usually the areas in poorest condition are the most heavily used portions of the winter ranges. Managers may be reluctant to try new or unproven vegetation management techniques because they do not want to sacrifice what little deer winter range they have. The result is that the stand continues to deteriorate and the amount of critical forage available to the deer herd continues to decline.

Most managers today realize they need to try something to keep their bitterbrush stands in good condition or risk complete loss. Techniques they find in the literature include burning, chaining, rolling or crushing, railing, rotobeating, and rotomowing (Driscoll 1963; Ferguson and Basile 1966; Giles 1970; Guinta and others 1978; Schnoegas and Zufelt 1965). Different results using different techniques may occur with the same treatment due to various factors, including time of year the treatment was performed, phenological stage of the plant, soil conditions, climatic conditions, ecotypic variation of the plant stands, or a combination of these factors. After considering the variables the manager chooses the technique(s) and tests it on a site. This is what the Bureau of Land Management has done in selecting the rotomowing technique to maintain the Juniper Mountain bitterbrush deer winter range.

TREATMENT AREA

The Juniper Mountain area is 10 miles (16 km) northwest of St. Anthony, Idaho. Soils in the area were once active sand dunes that have been vegetated by antelope bitterbrush, rabbitbrush (Chrysothamnus spp.), basin big sagebrush (Artemisia tridentata spp. tridentata), chokecherry (Prunus virginiana), Utah juniper (Juniperus osteosperma), and numerous forb and grass species. Precipitation in the area ranges from 16 to 18 inches (40.6 to 45.7 cm) annually.

Bitterbrush stands in the area have matured and are beginning to show a downward trend in conditions. The sagebrush is overaged and overgrown and is providing very little forage to wintering deer, but it does provide hiding cover. Junipers found in the area are scattered. At this time they do not appear to be increasing.

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[1] Paper presented at the Bitterbrush and Cliffrose Symposium, Salt Lake City, Utah, April 13-15, 1982.

[2] Wildlife Biologist, USDI Bureau of Land Management, Idaho Falls District, Idaho Falls, Idaho.

METHODS

The first phase of the two-part rotomowing project was a study to determine if pruning bitterbrush would have a beneficial or detrimental effect on the plants. The second phase was to evaluate the response of bitterbrush to the rotomowing technique and big game response to the project.

In 1978 a hand pruning study was started to determine the effect and response of pruning on bitterbrush. Three transects, each consisting of 20 tagged plants, were established. Transect A served as a control transect and the plants remained unpruned. Transect B was moderately pruned with some of the lower and upper branches removed. Transect C was heavily pruned with most of the plant growth removed except one or two stems. By having the different levels of treatment we hoped to determine which pruning intensity stimulated the most regrowth.

Leader growth was measured to the nearest centimeter on each of the tagged plants following each of the next 2 growing seasons. The summarized data were then plotted to illustrate the relationship between pruning intensity and leader growth (fig. 1). Results showed favorable response from heavily pruned plants. Based on these results and the literature, the large-scaled rotomowing treatment was started in 1980. An 8-ft (2.44 m) rotary mower was powered by a rubber-tired farm tractor. The mower blades were held 12 to 14 inches (30.5 to 35.6 cm) above the ground to chop up the decadent brush, but to not damage the seedlings and younger growth in the stand. Each treatment area was irregular in shape and greater than 5 acres (2.02 ha) in size, but no larger than 40 acres (16.2 ha).

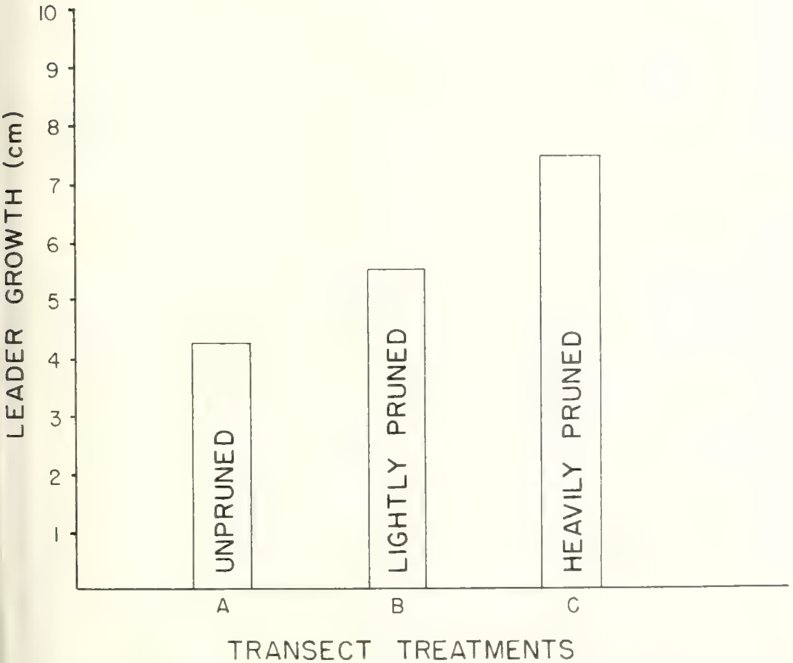

Figure 1.--Results from hand pruning study.

One treatment area was done in the fall and the others in the spring. Both the all and spring treatments were done on dormant plants. A total of 400 acres (162 a) were treated in the first project.

A 5-year monitoring study was established to document leader growth haracteristics, big game vegetation use, and visual changes. Leader growth, to the earest centimeter, is documented via four transects in the treated and untreated reas. The first years leader data were subjected to an analysis of variance. Six ig game utilization transects were established in the treated and untreated areas.

RESULTS AND DISCUSSION

Results from the 2-year hand pruning study indicated that pruning increased the production of bitterbrush (fig. 1). Plants on transect A had an average leader growth of 4.16 cm. Plants on transect B, the moderately pruned transect, had an average leader growth of 5.46 cm. Plants on transect C, the heavily pruned transect, had an average growth of 7.30 cm. Although the original transect data could not be statistically analyzed, the general pattern through the treatment levels was that growth increased when plants were heavily pruned. These results, along with some smaller treated test areas, indicated probable success on a larger treatment project.

Data results between the mowed and the unmowed areas showed a significant difference in the average leader growth. No significant difference could be found due to the season of treatment (table 1). Leader growth in the treated areas was 15.8 cm and 13.7 cm for the fall and spring treatments, respectively (fig. 2). During the same growing season the untreated areas only produced average leader growth of 3.41 cm and 7.22 cm for fall and spring treatment areas, respectively.

Table 1.--Analysis of variance showing mowed versus unmowed and the effect of season and treatment results

BITTERBRUSH ROTOMOWING PROJECT

$F_{(1,48)} = 7.17$, P

Fall Treatment	DF	MS	F
Mow versus unmow	1	1,228,998	246.34*
Error	48	4,989	
TOTAL	49	1,233,987	
Spring treatment			
Mow versus unmow	1	340,973	87.9*
Error	48	3,879	
TOTAL	49	344,852	
Season			
Spring versus fall	1	32,973	4.57 NS
Error	48	7,220	
TOTAL	49	40,193	

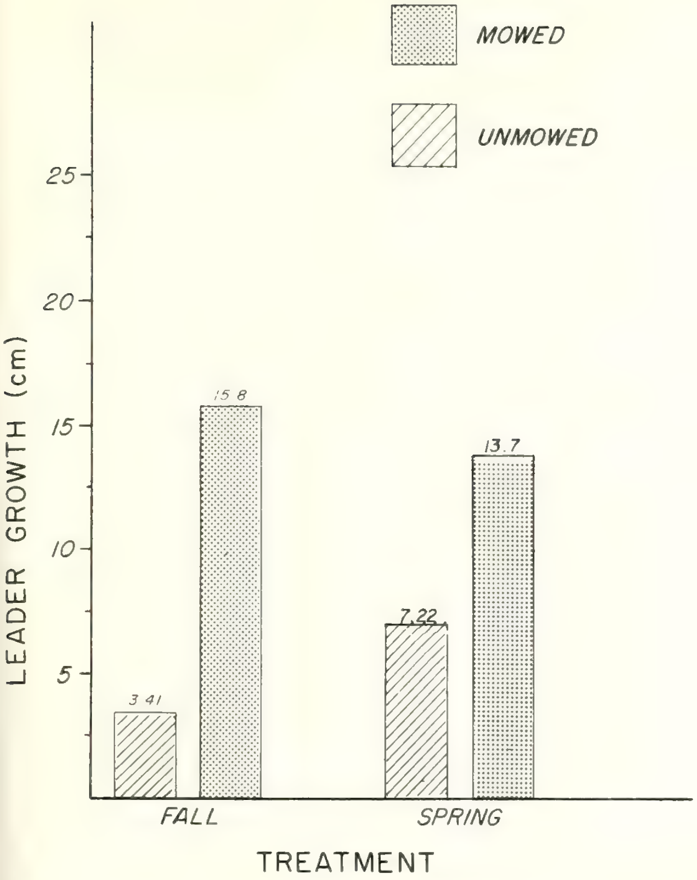

Figure 2.--Results from rotomowing showing leader growths from treatments in the fall and spring.

No mortality studies were done in the treatment areas prior to the project. Estimated mortality due to the treatment was less than 5 to 8 percent. This small loss is not expected to have a long-term detrimental effect on the productivity of the area.

Game and land managers want to know how long it will be before the treated areas produce usable forage and if temporary loss of production will be detrimental to wintering game. To answer these questions, the treatment areas were monitored throughout the winter months and vegetation utilization transects were read in the spring.

Results indicated that the treated areas had an average of 62 percent use (Idaho Fish and Game; and Hormay 1943) and adjoining untreated areas an average of 34 percent. Visual observations in the area supported the transect data. Deer were observed in the treatment areas every time they were visited; 77 animals were the most counted in a treatment area at one time. Because of such concentrations, the treatment areas had to be five acres (2.02 ha) or larger and numerous enough to accommodate the number of deer. The 25 to 40 acre (10.1 to 16.2 ha) treatment areas appear to be the most desired size, but there must be enough of them present to keep the use at an acceptable level.

Considerable flexibility is built into the use of this technique because season of treatment had no significant effect on the project success (fig. 2). Managers usually have to program for money in an annual work plan or have to accomplish a onsiderable amount of work during a limited time. The flexibility of the treatment llows two opportunities to accomplish the work during a field season when the money nd/or time is available.

Two unexpected results developed from the treatment technique. The first was the increased production of grasses and forbs. Although deer winter diets consist mainly of browse, forbs and some grasses are used, particularly in the spring when greenup begins.

The second unexpected result was the possible segregation of use areas. Deer appeared to use the treatment areas while they were snow free and available, and then they moved into taller stands of bitterbrush when the snow had covered the treatment areas. This foraging response relieves browsing pressure on the taller stands of bitterbrush and sagebrush during periods of low snow accumulation. After snow has covered the shorter forage, the deer have a basically untouched forage supply to carry them throught the deeper snow periods.

SUMMARY

Rotomowing antelope bitterbrush in the area west of St. Anthony, Idaho, initially appears to be a very useful technique in returning overaged and nonproductive big game winter ranges to highly desirable winter foraging areas. It can also be used on younger stands to avert deterioration.

A 5-year monitoring study was established to document the long term effects of the treatment. The first year's results showed there was an average leader growth, in the treated areas, of 15.8 cm and 13.7 cm for the fall and spring treatments, respectively. Big game use transects showed that deer, on an average, were able to use at least 62 percent of the vegetation during the first winter after a complete growing season. This high level of use indicates that treatment size and frequency must be considered during project layout in order to eliminate over-utilization and destruction by wintering big game.

Two unexpected results were gained from the project. There was increased grass and forb production in the treated areas. There also appeared to be a segregation of winter use areas by the deer.

PUBLICATIONS CITED

Driscoll, R. S. Sprouting bitterbrush in central Oregon. Ecology. 44(4): 820-821; 1963.

Ferguson, R. B.; Basile, J. V. Topping stimulates bitterbrush twig growth. J. Wildl. Manage. 30(4): 839-841; 1966.

Giles, R. H. Wildlife management techniques. 3rd ed. Ann Arbor, MI: Edwards Bros. Inc. 1970. 632 p.

Giunta, B. C.; Stevens, R.; Jorgenson, K. R.; Plummer, A. P. Antelope bitterbrush--an important wildland shrub. Publ. No. 78-12. Salt Lake City, UT: Utah State Division of Wildlife Resources; 1978. 48 p.

Hormay, A. L. A method of establishing grazing use of bitterbrush. Res. Note 34. Berkeley, CA: U.S. Department of Agriculture, Forest Service, California Forest and Range Experiment Station; 1943. 13 p.

Idaho Department of Fish and Game; U.S. Department of Interior Bureau of Land Management; and U.S. Department of Agriculture, Forest Service. Interagency guidelines for big game range investigations in Idaho; No Date. p. 18-19.

Schnoegas, E. R.; Zufelt, S. M. Rejuvinating decadent bitterbrush. Bishop, CA: U.S. Department of Agriculture, Forest Service, Inyo National Forest; 1965. 5 p. Mimeo.

Section 5. Animal Relationships

ENTOMOLOGY OF ANTELOPE BITTERBRUSH[1]

Malcolm M. Furniss[2]

ABSTRACT

Antelope bitterbrush is host to over 100 phytophagous insects, best known of which are species that defoliate, or infest fruits. Many other insect visitors range from perchers to pollinators to parasites and predators. In need of study are the susceptibility of ecotypes and hybrids; flower visitors; root infesters; plant disease vectors; and insect-plant community interrelationships.

INTRODUCTION

Antelope bitterbrush (*Purshia tridentata* [Pursh] D. C.) and its natural hybrids is a diverse shrub occurring in 11 western states and British Columbia on 340 million acres (138 million ha) over a wide range of climatic and soil conditions (Hormay 1943, Nord 1965). In its southern range, antelope bitterbrush intermingles with a close relative, desert bitterbrush (*Purshia glandulosa* Curran), insects of which are unstudied.

The use of antelope bitterbrush for browse by wild and domestic ungulates is addressed elsewhere in the symposium and in the literature (Basile 1967; Giunta and others 1978). What is not well publicized is its exceptional attractiveness to insects. Due largely to its wide occurrence and its abundant and fragrant yellow flowers, bitterbrush hosts an exceptional diversity of insects (Furniss 1972). Many are phytophagous in their habit, feeding on foliage, sucking juice, or infesting the bark or roots. Others are probably just perchers or somewhat chance visitors, perhap attracted to the flowers; for example, parasitic wasps that are kept alive by nectar until their various insects hosts become available. Doubtless, many insects spread pollen from flower-to-flower in their travels, including flies and beetles besides th fabled bees. Others, such as spiders and predacious insects, lurk or hunt for their prey amongst the canopy.

Few of these insects have been identified and even fewer have been studied to determine their biology. Generally, only an immature stage is observed doing damage, whereas species descriptions are invariably based on the adult stage. In such instances, specific identification is impossible until the adult is reared from associated immature specimens, often a difficult or fruitless undertaking.

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[1] Paper presented at Bitterbrush and Cliffrose Symposium, Salt Lake City, Utah. April 13-15, 1982.

[2] Principal Entomologist and Project Leader (retired), Forestry Sciences Laboratory, Moscow, Idaho 83843.

METHODS

I used a standard aerial sweep net to collect insects in flight around bitterbrush. The net was also held beneath branches that were struck to dislodge insects on them (fig. 1). I gathered more detailed information by patient, close observation of shrubs for insects, webbing, defoliation, or galls. Branches were carefully clipped so as not to disturb insects on them, then scrutinized through a hand lens or microscope. That way, mites, eggs, and small insects could be seen. Branches were also enclosed in clear plastic bags and taken to the laboratory in a cooler where insects including larvae and parasitic wasps showed up on the inside surface. These same bags served as rearing containers for insects such as mature caterpillars that were about to pupate. Less mature insects had to be provided fresh foliage or were reared on potted plants in the greenhouse. This method avoided parasitism and enabled more intensive observations than were possible in nature.

Diapause was sometimes a problem in rearing immature insects to adults. I usually split specimens into lots for different treatment consisting of exposure outdoors over winter or refrigeration for 90 days in moist material in petri dishes; however, both methods resulted in high mortality.

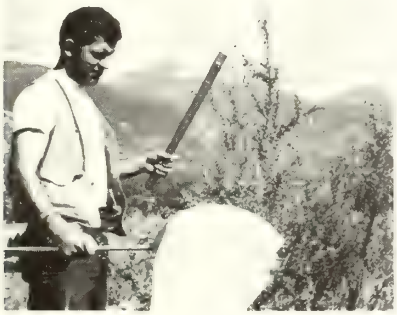

Figure 1.--Insects were collected from bitterbrush by various means including an aerial net held beneath branches that were struck with a stick.

INSECTS OF BITTERBRUSH

What insects inhabit bitterbrush? Or a better question: What insects inhabit or benefit from bitterbrush and its hybrids, and how do they differ elevationally, geographically, seasonally, and by shrub age, phenology, and community makeup?

Unfortunately, bitterbrush insects are so poorly known that relatively few examples are available to answer these questions. A small and biased portion of the shrub's distribution has been sampled--and then only for a limited number of insects. The collecting tends to occur where cooperating range scientists conduct their work or where an outbreak is handy or happens to be reported. Perhaps 90 percent of my records came from the following areas: South Fork Salmon River, Payette River, and Boise River (Idaho); in the vicinity of Ephraim, Utah; and restricted localities in northern California, northeastern Oregon, and western Montana.

Ten years ago I listed 81 insects and mites that feed on antelope bitterbrush (Furniss 1972). The list has grown past 100 since then, and several times that figure will perhaps be collected eventually. Not included in the list is a much larger number of predacious insects and spiders (the latter are virtually unidentified, though common), parasites (although many are known, and all the phytophagous species probably have them) and hordes of flower visitors. The roles of flower visitors are unstudied, but antelope bitterbrush is self-incompatible (Blauer and others 1975), and those insects likely play a profound role in pollination and hybridization.

TAXONOMIC DISTRIBUTION

The frequency of known phytophagous insects is shown in the following tabulation (Furniss 1972):

Order	Family	Species
Coleoptera	3	8
Diptera	1	3
Hemiptera	6	20
Homoptera	7	19
Lepidoptera	10	20
Orthoptera	1	5
Thysanoptera	1	1

Caterpillars (Lepidoptera), and sap-sucking insects (Hemiptera, Homoptera) constitute the most numerous species of insects collected from antelope bitterbrush, although their greater diversity does not preclude equal or greater importance of other orders. Because sap-sucking insects can transmit diseases of other plants, it is logical to investigate them as possible sources of disease on bitterbrush. So far, nobody has done so.

SOME COMMON AND IMPORTANT INSECTS

Most of the listed insects on bitterbrush are too poorly studied to permit their discussion. Some exceptions are presented here (see also Furniss and Barr 1975; and Furniss and Krebill 1972).

Species That Damage Flowers and Fruits

In April 1961, 600 flower buds were selected for weekly observation until seed drop, near Boise, Idaho (Ferguson and others 1963; Basile and others 1964). One hundred developing fruits on adjacent shrubs were collected weekly and examined for insect damage. Below are results of the study by percentage of plants damaged by insects (25 percent of seeds were normal):

Buds, flowers	
Thrips and unknown	6.5
Fruits, seeds	
Gelechiid caterperillars	5.0
Seed midge	6.8
Unknown insect	0.7
Shrivelled or spotted	56.0[3]

The seed midge (believed to be a species of Mayetiola) had never before been reported on bitterbrush. We found that eggs were laid between the calyx tube and husk early in May. After hatching, up to a dozen orangish larvae mine through the husk and evidently feed on the developing seed, causing it to shrivel and blacken. The mature larvae form a puparium that, because of its appearance is called the flax-seed stage. Infested fruits are easily recognized by their more narrow appearance and because they persist on the plants (fig. 2) after normal fruits have dropped.

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[3] About one-fifth of these seeds were black and shriveled, characteristic of the condition associated with feeding by Chlorochroa sayi Stal. The remainder were spotted, cause of which is unknown but thought to involve sucking insects.

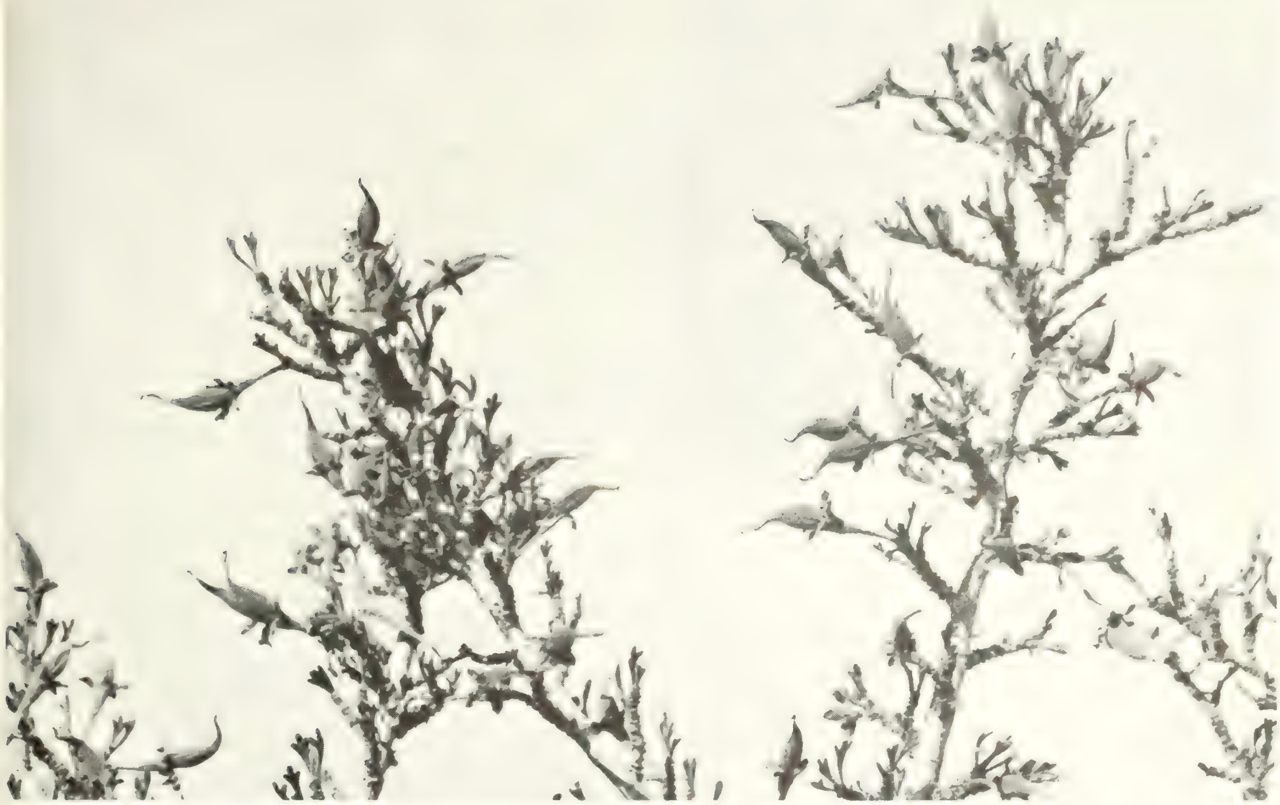

Figure 2.--Fruits infested with midge larvae did not grow to normal width, and were retained long after normal seeds had dropped (January photo).

The gelechiid caterpillars were Filatima sperryi Clarke and Gelechia mandella Busck. After hatching, the first-instar caterpillars bore into the fruits and feed on the nutritious seeds, plugging the entry with their silk (fig. 3). Later they bore out through a clean hole and spin a silken web and tunnel to which they retreat when not feeding on leaves. The partially eaten leaves dry and cling to the silk. I have seen foliage of young shrubs in Valley County, Idaho, heavily damaged by these caterpillars. The webs gave the shrubs a silvery halo appearance when backlighted.

Feeding on fruits by Say's stink bug, Chlorochroa sayi (Stal) (fig. 4), was the cause of nonviable, blackened seeds (Ferguson and others 1963; Basile and Ferguson 1964; Ferguson 1967).

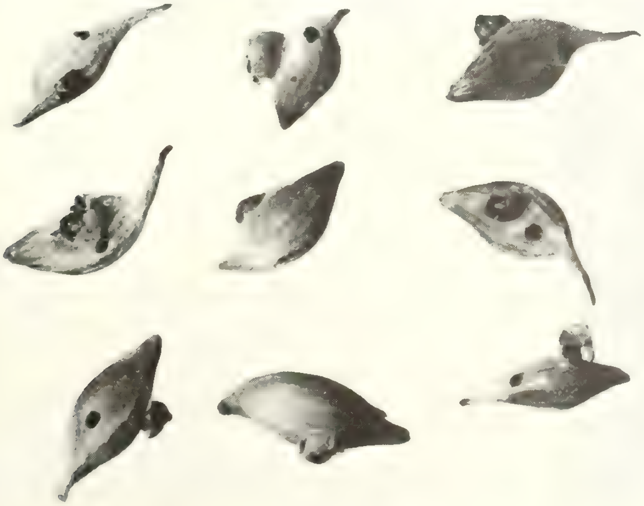

Figure 3.--Fruits destroyed by mining of first-instar gelechiid caterpillars. Entry holes are plugged by silk; caterpillars exit through open holes to feed thereafter on leaves.

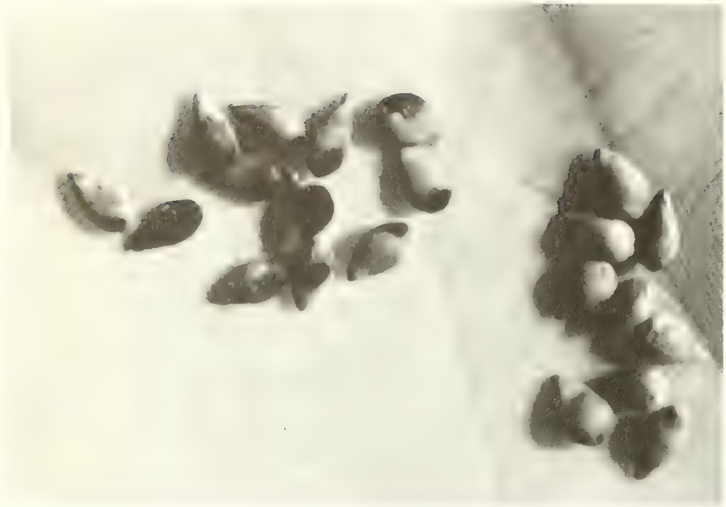

Figure 4.--Blackened appearance of seeds on left is due to feeding by stink bugs.

DEFOLIATORS

In a query to departments of fish and game in States and Provinces of Western North America and to other people involved with shrubs, I asked what insects were their greatest concern. Most replied that tent caterpillars (*Malacosoma californicum* Packard) on bitterbrush were most common. While I found this interesting, it is not representative of the true situation because the tents are conspicuous and most insects aren't. I have concluded after much experience that most insects are unseen by anyone. Their damage is often minor and nearly always subtle.

Although tent caterpillars have been recorded defoliating and killing bitterbrush over thousands of acres (Clark 1956), I have noted that tents (fig. 5) occur commonly on relatively few plants and seldom persist beyond a year. Nonetheless, this insect is potentially explosive, destined to give trouble at intervals. Duration of such outbreaks is apt to be short, however, due to a native virus that is rampant at high larval densities (Clark 1955; Clark and Thompson 1954).

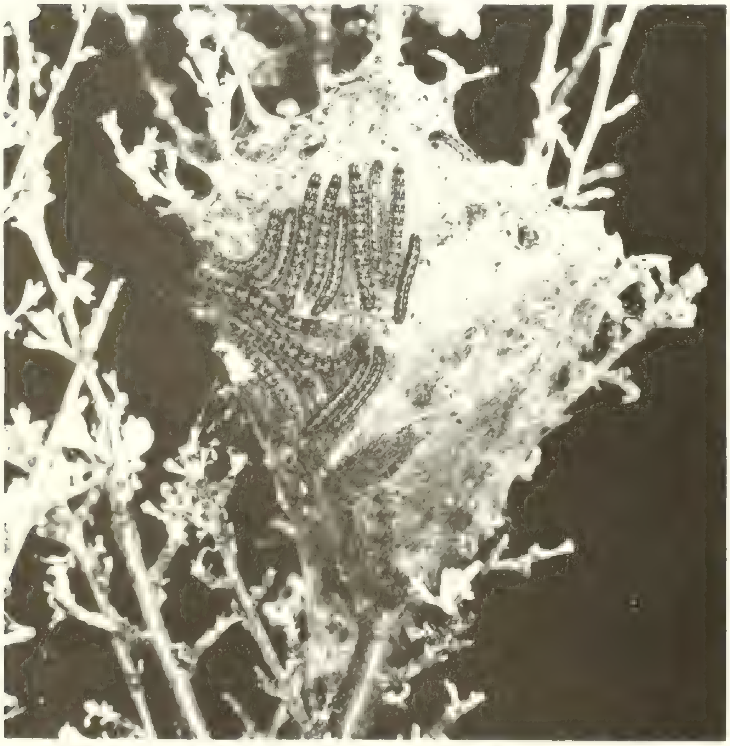

Figure 5.--Tent caterpillars congregate on their tent when not feedin

Recently, the walnut spanworm, Phigalia plumogeraria (Hulst) dramatically defoliated a seed orchard near Nephi, Utah (Furniss and Van Epps 1981; Van Epps and Furniss 1981). On May 17, 1979, the orchard appeared normal and plants were in full bloom on May 22. We now know that there had to be hundreds of thousands of larvae on the shrubs during those days--yet their presence went undetected until the next visit to the orchard on June 6 when the shrubs were found to be stripped of foliage and flowers. In the laboratory, I determined the walnut spanworm cycles through its larval (feeding) stage in an average of only 25 days at 70°F (21°C). The larvae had five instars, each exponentially greater in size than the previous one. The fourth and fifth instars (fig. 6) consume foliage at a rate many-fold that of earlier instars.

This event emphasizes a point: Vast populations of eggs or young caterpillars could be present, even in a small seed orchard, and nobody would know. Damage caused by loopers during their first two or three instars is subtle--consisting often of etching parts of leaf surfaces. But, with the increase in physical size to the fourth and especially the fifth instar, the larvae not only require much more food, but they are equipped with the strength and equipment to do so in large quantities. In these later instars, they reach out and guide edges of leaves into a notch in their labrum, whereby the leaf is fed into their cavernous mouths like hay entering a baler. Prior to the Nephi orchard defoliation, the walnut spanworm was unknown on bitterbrush, and unknown in Utah except for a few adults collected in flight.

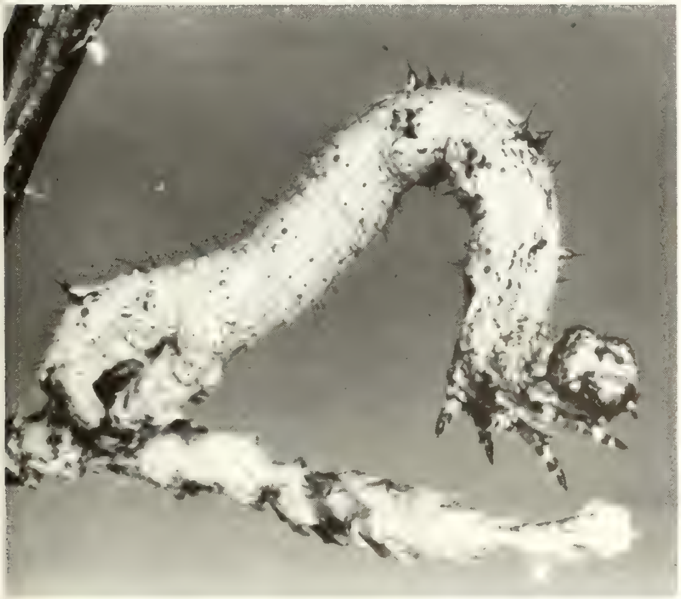

Figure 6.--A mature (fifth instar) walnut spanworm about to polish off the remnants of bitterbrush foliage. Such larvae stripped a Utah seed orchard of its leaves and developing fruits in 2 weeks.

The mountain mahogany looper, Anacamptodes animata profanata (Guen.), periodically attains epidemic numbers on bitterbrush. Prior to 1961, this species was known only from adult moths collected in flight without knowledge of its hosts or biology. Then it suddenly defoliated thousands of acres of curlleaf mountain mahogany in Owyhee County, Idaho (Furniss and Barr 1967). Intermingled bitterbrush and other shrubs were also defoliated. The infestation was reported by a rancher who was annoyed while riding his horse by webbing hanging from the tree-like mountain mahogany. I used that clue to relate the defoliation to presence of many pupae in the soil beneath defoliated shrubs. I subsequently learned that the pupae overwintered there and that adults emerged at night in the spring to lay eggs on the shrubs. The larvae vary amazingly in color and marking depending on factors such as crowding, host plant species, and environment, making their identification difficult.

Another defoliator, which I call the snailcase bagworm, Apterona crenuella Bruand (fig. 7), came here from Europe. Interestingly, the form (helix) that we have reproduces parthenogenetically--so we have only females, although both females and males occur in Europe. So far, not a great amount of damage has occurred to bitterbrush, which is but one of its many hosts.

Still another defoliator that appears to have been introduced, at least into Idaho, is the western tussock moth, Orgyia vetusta gulosa (Boisd.) (Furniss and Knopf 1971) (fig. 8). In the 1950's it defoliated bitterbrush and other shrubs near Idaho City. At that time, a smoke jumper contingent was in Idaho City, generating the possibility that some firefighter may have unknowingly brought back among his belongings the nucleus of this population. It seems to become epidemic only at fairly lengthy periods and is controlled by a native virus.

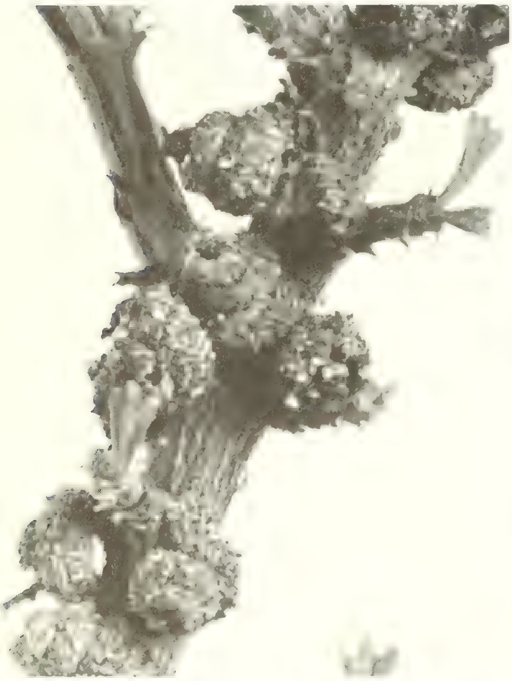

Figure 7.--Snailcase bagworm larvae on bitterbrush. The insect was introduced accidentally from Europe.

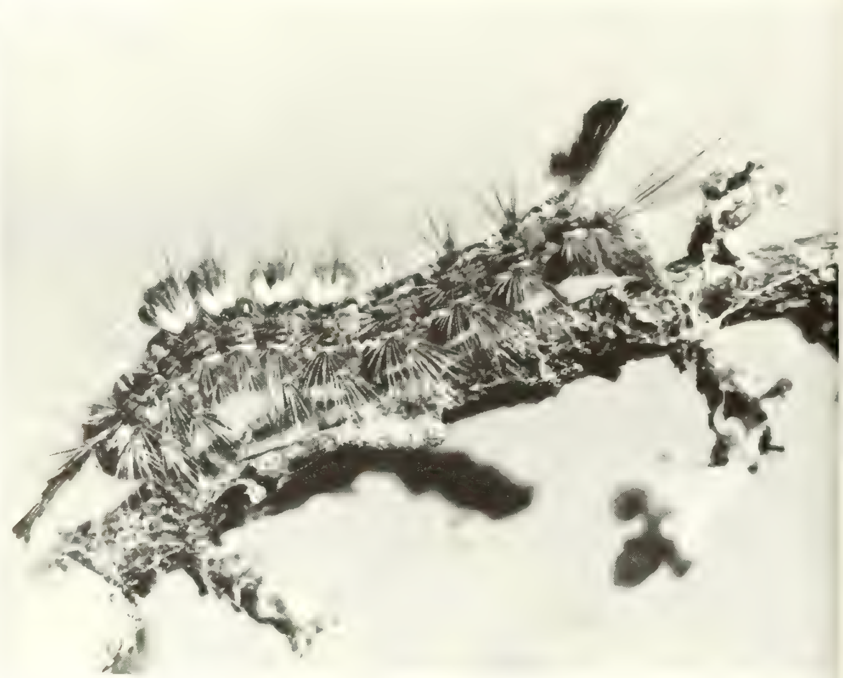

Figure 8.--This western tussock moth caterpillar is part of a disjunct population thought to have been accidentally introduced into southwestern Idaho from its more westward range.

CONCLUSIONS AND RECOMMENDATIONS

Although the diversity of insects on bitterbrush is actually a stabilizing factor in the plant community, the potential exists for outbreaks should natural controls fail or if new species are introduced.

Further research should include intensive study of predators (including spiders, which are virtually unstudied) and parasites of phytophagous insects; the kinds and relationships of flower visitors, including pollinators; root infesting insects; possible insect vectors of diseases of bitterbrush; differential susceptibility (or resistance) of hybrids and ecotypes to specific insects; surveying insect species and their abundance in the various bitterbrush provenances, and on hybrids and related species: Stansbury cliffrose and apache-plume; and insect-bitterbrush plant community interrelationships.

Whoever seeks to study bitterbrush insects will find that shrubs in general are looked on by many as undesirable, and likewise, shrub insects as being less important than those infesting trees. Researchers will also face difficulty in obtaining specific identification of bitterbrush insects because some are not described, others are described poorly, or the taxonomy of a group is confused. More often the insect stage concerned is immature and seldom included in the species description. Fortunately, however, I have usually succeeded in getting help from taxonomists to unravel the identity of important species (see Acknowledgments).

Caution should be taken to avoid directing research only on species causing the most obvious current damage or which are most abundant at the time. Some insects have remained at low levels for decades, only to explode and defoliate and kill extensive stands of shrubs. A concerned person should make every effort to study everything about those insects--then interpret their importance.

Finally, I recommend keeping an eye on other components of the bitterbrush community. Insects and other factors that adversely or beneficially affect the regeneration, vigor, and longevity of other vegetation can affect bitterbrush as profoundly as insects acting directly on bitterbrush. For those reasons, a good knowledge of community relationships is needed to develop management practices that benefit more than they harm.

PUBLICATIONS CITED

Basile, J. V. An annotated bibliography of bitterbrush (Purshia tridentata [Pursh] D. C.). Res. Pap. INT-44. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1967. 27 p.

Basile, J. V.; Ferguson, R. B. Say stinkbug destroys bitterbrush seed. J. Range Manag. 17: 153-154; 1964.

Basile, J. V.; Ferguson, R. B.; Furniss, M. M. Six-legged seed eaters. Idaho Wildlife Rev. 17(3): 5-7; 1964.

Blauer, A. C.; Plummer, A. P.; McArthur, E. D.; Stevens, R.; Giunta, B. C. Characteristics and hybridization of important Intermountain shrubs. I. Rose family. Res. Pap. INT-169. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1975. 35 p.

Clark, E. C. Observations on the ecology of a polyhedrosis of the Great Basin tent caterpillar Malacosoma fragilis. Ecology 36: 373-376; 1955.

Clark, E. C. The Great Basin tent caterpillar in relation to bitterbrush in California. Calif. Fish and Game 42: 131-142; 1956.

Clark, E. C.; Thompson, C. G. The possible use of microorganisms in the control of the Great Basin tent caterpillar. J. Econ. Entomol. 47: 268-272; 1954.

Ferguson, R. B.; Furniss, M. M.; Basile, J. V. Insects destructive to bitterbrush flowers and seeds in southwestern Idaho. J. Econ. Entomol. 56: 459-462; 1963.

Furniss, M. M. A preliminary list of insects and mites that infest some important browse plants of western big game. Res. Note INT-155. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1972. 16 p.

Furniss, M. M.; Barr, W. F. Bionomics of *Anacamptodes clivinaria profanata* (Lepidoptera: Geometridae) on mountain mahogany in Idaho. Univ. of Idaho Agr. Exp. Sta. Res. Bull. 73; 1967. 24 p.

Furniss, M. M.; Barr, W. F. Insects affecting important native shrubs of the northwestern United States. Gen. Tech. Rep. INT-19. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1975. 64 p.

Furniss, M. M.; Knopf, J. A. E. Western tussock moth. For. Pest Leafl. 120. Washington, DC: U.S. Department of Agriculture, Forest Service; 1971. 4 p.

Furniss, M. M.; Krebill, R. G. Insects and diseases of shrubs on western big game ranges. In: Useful wildlife shrub symposium proceedings. Rep. INT-1. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1972. 218-226.

Furniss, M. M.; Van Epps, G. A. Bionomics and control of the walnut spanworm, *Phigalia plumogeraria* (Hulst), on bitterbrush in Utah. Great Basin Naturalist 41: 290-297; 1981.

Giunta, B. C.; Stevens, R.; Jorgensen, K. R.; Plummer, A. P. Antelope bitterbrush--an important wildland shrub. Utah Div. Wildlife Resources Publ. No. 78-12; 1978. 48 p.

Hormay, A. L. Bitterbrush in California. Res. Note 34. Berkeley, CA: U.S. Department of Agriculture, Forest Service, California Forest and Range Experiment Station; 1943. 12 p.

Nord, E. C. Autecology of bitterbrush in California. Ecol. Monogr. 35: 307-334; 1965.

Van Epps, G. A.; Furniss, M. M. Walnut spanworm: a new defoliator of Utah's bitterbrush. Utah Science 42: 80-85; 1981.

NUTRITIVE VALUE OF ANTELOPE AND DESERT BITTERBRUSH, STANSBURY CLIFFROSE, AND APACHE-PLUME[1]

Bruce L. Welch, Stephen B. Monsen, and Nancy L. Shaw[2]

ABSTRACT

For range plants that are grown for animal consumption, nutritive value is of paramount importance, both qualitatively and quantitatively. A brief description is given concerning the digestive process and needs of consuming animals as a basis for judging the nutritive value of bitterbrush, cliffrose, and Apache-plume. Also discussed are the cyclic use of antelope bitterbrush and the feasibility of improving the winter level of its nutrients.

INTRODUCTION

For range plants that are grown for animal consumption, nutritive value is of paramount importance, both qualitatively and quantitatively. The nutritive value of any plant is judged by its ability to supply the nutrients to meet the physiological requirements of the consuming animal. Quantitatively the nutrient needs of animals vary according to species, age, size, and activity (National Academy of Sciences 1975; Maynard and others 1979). Qualitatively, nutrient needs of animals can be classified as energy-producing compounds, protein, minerals, and vitamins. (Water is also an important nutrient but is not considered in this paper.)

THE DIGESTIVE PROCESS

A basic understanding of the digestive processes and how different digestive racts affect the digestive process is important in understanding the nutrient needs f range animals.

By definition, digestion is a process in which food is broken down into small article size and finally solubilized for absorption and use in the body (Maynard and thers 1979). Ingestion is the first step in the digestion process. In the mouth, ood is broken up by mastication and mixed with saliva, which acts as a food softener nd a lubricant. Large differences exist among animal species as to the extent food s masticated in the mouth. Ruminant animals such as cattle, sheep, and mule deer oroughly grind grass by regurgitating and remasticating the food. Cattle are poor grinding small seeds, whereas sheep and mule deer are able to break up small seed.

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[1] Paper presented at Bitterbrush and Cliffrose Symposium, Salt Lake City, Utah, pril 13-15, 1982.

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From the mouth, the food moves down the esophagus into the stomach. The stomach can be a single compartment or four compartments. For the single compartment stomach (the abomasum), ingested food is exposed to hydrochloric acid and pepsin secreted by the gastric mucosa. Some microbial fermentation may occur in the single compartment stomach. From the stomach, the food passes into the small intestine where digestion continues and adsorption starts. Limited nutrient absorption and digestion occur in the last organ of the digestion tract, the large intestine.

The digestive tract of an animal includes the mouth, esophagus, stomach, small intestine, and large intestine. Digestive fluids are pumped into the tract from the liver and pancreas. Glands located along the digestive tract in the mucus lining also secrete digestive fluids into the tract. Based on the presence or absence of a compound stomach or large cecum, animals can be divided into two great groups; those depending on microbial fermentation to digest highly fibrous foods, and those lacking the ability to support microbial fermentation. Because the most economically important range animals have fermentation types of digestion (including cattle, sheep, goats, deer, elk, horses)[3], a detailed discussion of their digestion process is needed.

Animals that depend on microbial fermentation can be divided into two groups; those with a compound stomach, called ruminants (cattle, sheep, goats, deer, elk), and those with a simple stomach and a large cecum (horses, rabbits). The ruminant stomach is divided into four compartments, rumen, reticulum, omasum, and abomasum. The rumen is the first and by far the largest of the compartments. Hastily eaten food is stored in the rumen under conditions that favor microbial fermentation--warmth (38° to 42°C), slight acidity (pH 6.8 to 6.0), and moisture. The food later is regurgitated, thoroughly chewed, and swallowed back into the rumen for additional microbial digestion. Muscular contractions by the rumen and reticulum keep the highly moistened food mass mixed. The coarse, less dense portion of the food mass is kept in the rumen by the muscular contractions of the rumen and reticulum for additional digestion. Macerated-digested food particles and the bodies of millions of microorganisms are forced into the reticulum and pass on to the omasum. In the omasum, large quantities of water are absorbed that concentrate the macerated-digested food mass and microbial mass. From the omasum the food and microbial mass is forced by peristaltic action into the abomasum where true digestion begins.

During the fermentation process, volatile fatty acids are formed, which in turn are absorbed directly by the rumen into the bloodstream. Volatile fatty acids are the major supplier of energy to the animal. Through microbial fermentation, the 10 essential amino acids needed by the animal are synthesized by the rumen microorganisms from plant protein, urea, and inorganic nitrogen. These amino acids may occur free in the rumen to be absorbed through the rumen wall and enter the bloodstream, or may be used to build microbial protein that becomes available to animals through regular enzymatic digestions. Rumen microorganisms also synthesize all the B vitamins needed by the animal. For animals capable of supporting microbial fermentation, protein quality and B vitamins are not a concern.

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[3] For nonfermentation digestion tracts, the reader is referred to the following publications: Ensminger, M. E., and C. G. Olentine, Jr. 1978. Feeds and nutrition--abridged. The Ensminger Publ. Co., Clovis, California; Maynard, L. A., J. L. Lossli, H. F. Hintz, and R. C. Warner. 1979. Animal nutrition. 7th Ed. McGraw Hill Co., New York.

NUTRIENT NEEDS OF RANGE ANIMALS

From a quantitative point, the nutrient needs of animals vary according to species, age, size, and activity (National Academy of Sciences 1975; Maynard and others 1979). Qualitatively, nutrient needs of animals can be classified as follows: energy-producing compounds, protein, minerals, and vitamins.

Energy-Producing Compounds

Energy-producing compounds make up the single largest class of nutrients needed by animals (Dietz 1972; National Academy of Sciences 1975). Energy is needed to drive the various physiological processes of the body, and to provide movement and heat. Energy can be derived from a variety of compounds, including sugars, fats, pectins, starch, and protein, and in the case of ruminants and others with fermentation abilities, indirectly from cellulose and hemicellulose (Dietz 1972; National Academy of Sciences 1975; Maynard and others 1979). Some plant products including monoterpenoids and lignin do not furnish energy to the animal (Cook 1972; Short and others 1972; Maynard and others 1979).

The energy needs of animals are expressed in several forms such as total digestible nutrients, digestible energy, or metabolizable energy. Total digestible nutrients (TDN) is the sum of all the digestible organic compounds (proteins, sugars, cellulose, and so forth) with the digestible crude fat component being multiplied by the heat factor 2.25 (Maynard and others 1979). The TDN requirement of an animal is expressed as kilograms per animal per day or as a percent of the diet. Digestible energy (DE) is calculated by subtracting the gross calories in the feed from the calories in the feces (Maynard and others 1979). DE requirement of an animal is expressed as megacalories per animal per day or as megacalories per kilogram of dry matter. DE does not take into consideration losses of energy in the urine and in the form of combustible gases. When the energy losses in the urine and in the combustible gases have been subtracted, the remaining energy is called metabolizable energy (ME). Measuring the energy lost in the urine and combustible gases is expensive and subject to large experimental error (Dietz 1970). The ME requirement of an animal is expressed as megacalories per animal per day or as megacalories per kilogram of dry matter (Maynard and others 1979).

Energy needs of range animals vary according to weight and activity of the animal. Larger animals require more kilograms of TDN per day for a given activity han do smaller animals. A lactating female requires more kilograms of TDN per day than a nonlactating female of similar weight. On a constant weight basis, lactation equires a greater amount of energy than do other types of activities. Lactation s followed in descending order of energy needed by fattening, growing, gestation, nd maintenance (National Academy of Sciences 1975).

Protein

Protein in animal bodies makes up a large, chemically related, but physiologi- ally diverse group of compounds. Protein is the major organic compound of the rgans and soft tissues of the body. All proteins are made from a common set of uilding blocks known as amino acids. Proteins are the chief component in a number bodily structures: (1) skeleton muscle for external movement; (2) smooth muscle r internal movement (including breathing and the passage of food through the gestive tract); (3) cardiac muscle for the movement of blood; (4) tendons and igaments for tying together body parts such as bones, muscles, and organs; (5) gans and glands such as the stomach, eye, pituitary, and skin (with its covering hair); and (6) other structures including hemoglobin, cytochromes, and membrance.

Another functionally important group of protein compounds is enzymes, which provide the framework in which the chemical reactions of the body take place.

Because proteins are involved in so many bodily functions, the animal needs a liberal and continuous supply of them. Like energy, the protein requirement varies according to the weight and activity of the animal. For ruminants and other animals that have fermentation type digestive systems (horses, rabbits, burros), the quality of the protein is not important, only the quantity. The animal's protein requirement is expressed as grams per day of digestible protein or as a percent digestible protein in the diet. The requirement may also be expressed as grams per day of crude or total protein in the diet. As with energy, the greather the weight of the animal, the higher the protein needs. This assumes that activity is held constant. Protein needs for the various animal activities with body weight held constant is in the same order as for energy (National Academy of Sciences 1975).

Minerals

Mineral elements essential for the health of animals number about 15. Of these, seven are considered major elements: sodium, chlorine, calcium, phosphorus, magnesium potassium, and sulfur. The remaining eight are classified as trace elements: iodine, iron, copper, molybdenum, cobalt, manganese, zinc, and selenium. These essential mineral elements constitute the major components of bones and teeth, maintain osmotic relations and acid-base equilibrium, play an important role in regulating enzymatic systems and muscular contraction, and are constituents of most organic compounds. They are also important in energy transfer (Ensminger and Olentine 1978; Maynard and others 1979).

Under most conditions, calcium and phosphorus are the mineral elements of major concern. Animal needs for calcium and phosphorus are expressed as grams per day per animal or as a percent of the diet. Larger animals under similar activity need greater amounts of calcium and phosphorus than do smaller animals. With size held constant, lactating animals require the most amount of calcium and phosphorus, followed by growth, fattening, gestation, and maintenance. The reader should note the requirement for energy and protein is greater for the fattening activity than for the growing activity (National Academy of Sciences 1975).

Vitamins

Vitamins are organic compounds needed by the body in relatively small amounts. They are unrelated chemically, but function as metabolic regulators (Maynard and others 1979). For animals capable of supporting microbial fermentation, only vitamin A is of major concern. Vitamin A combines with a specific protein of the eye to produce visual purple. Vitamin A is also important in normal development of bones in normal power of disease resistance, and in maintaining healthy epithelium tissues. Because this vitamin is manufactured from the plant precursor carotene, the vitamin A requirement is expressed in terms of carotene, either as milligrams per animal per da or milligrams per kilogram of dry matter. With size held constant a lactating animal requires the most carotene, followed by growth, fattening, gestation, and maintenance (National Academy of Sciences 1975).

Antelope bitterbrush, normally considered a winter forage for mule deer (Giunta and others 1978), is one of the major shrubs in their fall diet (Leach 1956; Tueller 1979; Medin[4]). After fall, the amount of antelope bitterbrush in the mule deer diet drops and the amount of big sagebrush or other shrubs increases to a peak in midwinter and starts declining in midspring (Leach 1956; Tueller 1979; Medin[4]). Leach (1956) observed on California winter ranges that the low use of bitterbrush during the winter months is not correlated with availability. A report on Colorado winter ranges by Medin[4] agrees. Welch and Andrus (1977) reported heavy winter mule deer use on big sagebrush and rosehips but none on antelope bitterbrush on a Utah range. Even on ranges where the composition of antelope bitterbrush and big sagebrush was equal (27 and 29 percent, respectively) the mule deer consumed much more big sagebrush during winter (Leach 1956). This cyclic heavy use of antelope bitterbrush in the fall to big sagebrush use in the winter appears to be independent of the winter's severity (mild-open to cold with deep snow) (Leach 1956). Tueller (1979), however, attributed the low level of antelope bitterbrush in the diet of wintering mule deer in Nevada to short supplies of bitterbrush.

The Leach (1956), and Medin[4] studies suggest that antelope bitterbrush may be primarily a fall forage for mule deer, that deer tend to switch from antelope bitterbrush to big sagebrush or other browse during the winter months, and that this switch is not necessarily due to short supplies of antelope bitterbrush. The importance of antelope bitterbrush as a winter forage for mule deer may not be as much as commonly held. But, its position as an important fall forage for mule deer needs to be emphasized.

Winter Digestibility

As explained earlier, total digestible nutrients is a measurement of energy in a forage. The total digestible nutrient requirement for wintering sheep (maintenance) is 55 percent (National Academy of Sciences 1975). Total digestible nutrient requirement for wintering mule deer is unknown but is probably close to that of sheep. Reported total digestible nutrient levels for antelope bitterbrush range from 39.7 to 54.8 percent; the mean is 47.5 percent (Bissell and others 1955; Dietz and others 1962; Smith 1952; 1957; Urness and others 1977). This compares to 64.8 percent for curlleaf mahogany, 63.4 for big sagebrush, 60.8 for juniper, 48.4 for mountain mahogany, 38.9 for chokecherry, and 36.2 for Gambel oak (table 1). Only curlleaf mahogany, big sagebrush, and juniper meet or exceed the total digestible nutrient equirement of wintering sheep and probably wintering mule deer. In general, dormant rasses are higher in total digestible nutrients than are most shrubs, and evergreen hrubs contain more digestible energy in the winter than do deciduous shrubs (Cook 972; Welch 1981).

In vitro digestibility trials show that evergreen shrubs such as big sagebrush nd curlleaf mahogany are more digestible than the deciduous shrubs (table 2). The *in vitro* digestibility of antelope bitterbrush is 25.1 percent. This compares to big sagebrush at 55.6 percent, black sagebrush at 53.1, chokecherry at 38.2, Gambel oak at 29.5, and mountain mahogany at 24.3 (see table 2 for other shrubs and references).

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[4] Medin, D. E. Unpublished data on file at the Shrub Sciences Laboratory, Provo, tah.

Table 1.--Total digestible nutrients of winter shrubs

Shrub	Total digestible nutrients (percent)	Reference*
Curlleaf mahogany	64.8	2, 3, 6
Big sagebrush	63.4	1, 2, 3, 4, 5, 6
Juniper	60.8	2, 3
Mountain mahogany	48.4	3, 4, 6
Bitterbrush	47.5	2, 3, 4, 5, 6
Chokecherry	38.9	3
Gambel oak	36.2	3

*Reference
1 - Smith 1950.
2 - Smith 1952.
3 - Smith 1957.
4 - Dietz and others 1962.
5 - Bissell and others 1955.
6 - Urness and others 1977.

Table 2.--*In vitro* digestibility of winter shrubs

Shrub	Dry matter digestibility (percent)	Reference*
Big sagebrush	55.6	1, 2, 3, 4, 5, 6
Black sagebrush	53.1	8
Curlleaf mahogany	51.6	1, 4
Rosehips (Sweetbrier rose)	49.1	4
Rubber rabbitbrush	45.9	6
Winterfat	44.7	8
Chokecherry	38.2	7
Saskatoon serviceberry	34.6	6
Gambel oak	29.5	5
Bitterbrush	25.1	1, 4, 6
True mahogany	24.3	1, 4

*Reference
1 - Urness and others 1977.
2 - Wallmo and others 1977.
3 - Sheehy 1975.
4 - Welch and Pederson 1981.
5 - Kufeld and others 1981.
6 - Ward 1971.
7 - Uresk and others 1975.
8 - Welch and others, in press.

Winter Crude Protein Levels

The protein requirement for wintering sheep and probably for mule deer is 8.9 percent (National Academy of Sciences 1975). Antelope bitterbrush has a reported winter crude protein content of 7.9 percent, desert bitterbrush 8.0 and cliffrose 8.4

(see table 3 for references). These values compare to big sagebrush at 10.7 percent, curlleaf mahogany at 10.1, fourwing saltbush at 9.6, chokecherry at 8.5, mountain mahogany at 7.8, Saskatoon serviceberry at 5.7, and Gambel oak at 5.4 (see table 3 for additional shrubs and for references). Only big sagebrush, curlleaf mahogany, and fourwing saltbush meet or exceed the crude protein requirement. In general, evergreen shrubs are higher in the winter level of crude protein than are deciduous shrubs, and deciduous shrubs are much higher in the winter level of crude protein than are dormant grasses (Cook 1972; Welch 1981).

Table 3.--Winter crude protein level of shrubs

Shrub	Crude protein (percent dry matter)	Reference*
Big sagebrush	10.7	1,2,3,4,6,8,9,10,12
Black sagebrush	10.2	10,12
Curlleaf mahogany	10.1	3,7
Fourwing saltbush	9.6	11
Chokecherry	8.5	3,5,10
Rocky Mountain juniper	8.5	1
Cliffrose	8.4	5
Utah juniper	8.0	3,5
Desert bitterbrush	8.0	3
Antelope bitterbrush	7.9	1,3,4,7,8,9
Mountain mahogany	7.8	1,5,8
Shadscale	7.7	10
Gardner saltbush	7.2	10
Rubber rabbitbrush	6.8	1,10
Saskatoon serviceberry	5.7	3,10
Gambel oak	5.4	5

*Reference

1 - Dietz and others 1962.
2 - Welch and McArthur 1979.
3 - Tueller 1979
4 - Bissell and others 1955.
5 - Smith 1950.
6 - Smith 1952.
7 - Trout and Thiessen 1973.
8 - Medin and Anderson 1979 (data converted to dry matter basis).
9 - National Academy of Sciences 1975.
10 - National Academy of Sciences 1958.
11 - Welch and Monsen 1981.
12 - Sheehy 1975.

Winter Phosphorus Levels

The phosphorus requirement for wintering sheep and probably mule deer is 0.24 ercent (National Academy of Sciences 1975). Winter phosphorus content of antelope nd desert bitterbrush is 0.13 and 0.10 percent, respectively (table 4). Both are ell below the requirement. Even though aspen (0.23 percent), juniper (0.22), big agebrush (0.22), Gardner saltbush (0.21), and other shrubs contain significantly igher levels of winter phosphorus than the two bitterbrushes, they do not meet the hosphorus winter requirement (see table 4 for additional shrubs and for references). n general, shrubs are significantly higher in winter levels of phosphorus than are ormant grasses (Cook 1972; Welch 1981).

Table 4.--Winter phosphorus level of shrubs

Shrub	Phosphorus (percent dry matter)	Reference*
Aspen	0.23	8
Big sagebrush	.22	1,2,3,4,5,6
Rocky Mountain juniper	.22	8
Gardner saltbush	.21	5
Chokecherry	.18	2,7
Saskatoon serviceberry	.17	2,7
Curlleaf mahogany	.17	2,3
Black sagebrush	.16	5
Fourwing saltbush	.15	4
Rubber rabbitbrush	.14	1,4,8
Mountain mahogany	.13	1,6
Antelope bitterbrush	.13	1,2,3,4,6
Shadscale	.12	4,5
Desert bitterbrush	.10	2

*Reference
1 - Dietz and others 1962
2 - Tueller 1979
3 - Trout and Thiessen 1973
4 - National Academy of Sciences 1958
5 - National Academy of Sciences 1964
6 - Medin and Anderson 1979 (data converted to dry matter basis)
7 - Dietz 1972
8 - Short and others, unpublished data

Winter Carotene Levels

All shrubs furnish enough carotene to meet the winter vitamin A requirements for sheep and mule deer; dormant grasses furnish very little carotene. Range animals consuming large amounts of dormant grass could easily develop a vitamin A deficiency (Cook 1972; Welch 1981).

As a winter forage, antelope bitterbrush supplies more carotene, crude protein, and phosphorus, but less energy than does dormant grass. Desert bitterbrush and cliffrose may supply a little more crude protein and energy than does antelope bitterbrush. Several shrubs such as big sagebrush, fourwing saltbush, and curlleaf mahogany supply significantly more crude protein, phosphorus, and energy to the consuming animal than does antelope bitterbrush. The gradual dietary switch from an antelope bitterbrush base to a big sagebrush base observed by Leach (1956) and Medin[5] could be the result of mule deer selecting for a higher nutritive plane in the diet in response to increasing environmental stress.

Improving the Winter Level of Nutrients

Dietz and others (1962) reported that the total digestible nutrient content of a winter sample of antelope bitterbrush containing a large amount of wintering green leaves was 52.5 percent. Presence of green leaves is an indicator of a high level of nutrients (Ensminger and Olentine 1978). The question becomes, was the antelope genetically superior in producing wintering green leaves, or was the abundance of leaves due to unusual environmental conditions such as a warm-moist fall or winter? Alderfer (1976) and Monsen[6] have observed that some populations of antelope bitterbrush retain more green leaves during the winter than others. Giunta and others (1978) report genetic differences among antelope bitterbrush in growth habit, adaptation, and so forth. If genetic factors are important in determining winter leafiness, then breeding and selection programs could be devised to maximize leafiness and winter nutrient content.

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[5] Medin, D. E. Unpublished data on file at the Shrub Sciences Laboratory, Provo, Utah.

To broaden our understanding of the role that genetics might play in determining leafiness and crude protein, we undertook a study to determine the variation of winter leafiness, crude protein, and *in vitro* digestibility among five accessions of antelope bitterbrush, two accessions of desert bitterbrush, and one accession each of cliffrose and Apache-plume. All accessions were grown in a uniform garden. Desert bitterbrush, cliffrose, and Apache-plume were included because they can be hybridized with antelope bitterbrush (Blauer and others 1975; Koehler and Smith 1981). Significant variation among accessions would indicate that genetic factors are important in determining winter leafiness, crude protein levels, and *in vitro* digestibility. Locations of the accessions by county and state are given in tables 5 and 6.

Table 5.--Winter crude protein levels among accessions of Apache-plume, antelope bitterbrush, desert bitterbrush, and cliffrose grown in a uniform garden. Data expressed on a dry matter basis

Accession	County and State	Crude protein (percent)
Fallugia paradoxa (Apache-plume)	Sevier, Utah	4.8[*]
Purshia tridentata (Antelope bitterbrush)	Moffatt, Colorado	5.9^{a}
Purshia tridentata	Juab, Utah	6.6^{b}
Purshia tridentata	Carbon, Utah	6.8^{b}
Purshia tridentata	Ada, Idaho	6.9^{b}
Purshia tridentata	Lassen, California	7.9^{c}
Purshia glandulosa (Desert bitterbrush)	Washington, Utah	8.6^{cd}
Cowania mexicana ssp. *stansburiana* (Cliffrose)	Utah, Utah	8.8^{cd}
Purshia glandulosa	Mono, California	9.3^{d}

[*] Means sharing the same letter superscript are not significantly different at the 95 percent level.

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[6] Monsen, S. B. Unpublished data on file at the Forestry Sciences Laboratory, Boise, Idaho.

Table 6.--Winter leafiness among accessions of Apache-plume, antelope bitterbrush, desert bitterbrush, and cliffrose grown in a uniform garden. Data expressed on a dry matter basis

Accession	County and State	Winter leaves (percent)
Purshia tridentata (Antelope bitterbrush)	Ada, Idaho	5.9^{a*}
Purshia tridentata	Moffat, Colorado	7.4^{ab}
Purshia tridentata	Carbon, Utah	9.0^{abc}
Purshia tridentata	Juab, Utah	13.1^{bc}
Purshia tridentata	Lassen, California	15.1^{c}
Fallugia paradoxa (Apache-plume)	Sevier, Utah	27.3^{d}
Cowania mexicana ssp. *stansburiana* (Cliffrose)	Utah, Utah	47.5^{e}
Purshia glandulosa (Desert bitterbrush)	Washington, Utah	49.5^{e}
Purshia glandulosa	Mono, California	50.5^{e}

*Means sharing the same letter superscript are not significantly different at the 95 percent level.

From the uniform garden, we collected current year growth (stems with leaves, if present) from five plants for each accession. The five plants were chosen at random. Nitrogen content was determined by the Kjeldahl method and the crude protein level calculated (Association of Official Analytical Chemists 1980). Crude protein was expressed as a percent of dry matter. To determine *in vitro* digestibility, we used the Pearson (1970) *in vitro* digestibility method.

We used completely random analysis of variance to detect significance among the nine shrub accessions. Hartley's test ($\alpha=0.05$) was used to determine significant differences among accession means (Sendecor and Cochran 1967). Percentages were transformed to arcsin to avoid inequalities in the variance.

The winter crude protein content means for the accessions of antelope bitterbrush, desert bitterbrush, Stansbury cliffrose, and Apache-plume were 6.8, 9.0, 8.8, and 4.8 percent (dry matter basis), respectively. Significant differences in the crude protein levels were attributed to accessions (table 5). The Apache-plume was significantly ($\alpha=0.05$) lowest of all accessions tested. Desert bitterbrush from Mono County in California, contained the highest crude protein content of all accessions (9.3 percent), although not significantly higher than the Stansbury cliffrose (8.8), and the desert bitterbrush (8.6) from Washington County, Utah. Antelope bitterbrush from Moffat County, Colorado, contained significantly more (5.9) crude protein than the Apache-plume, but was significantly lower than the remaining. The antelope bitterbrush from Lassen County, California, contained significantly higher levels of crude protein (7.9) than the other antelope bitterbrush, but less than the two desert bitterbrush and Stansbury cliffrose accessions.

Winter leafiness also varied significantly among the accessions (table 6). The two desert bitterbrush and the cliffrose were significantly more leafy than the others. Apache-plume was significantly more leafy than any of the five antelope bitterbrush, but significantly less than the two desert bitterbrush and the cliffrose. Leafiness ranged from 5.9 to 15.1 percent of current year growth among the five accessions of antelope bitterbrush.

In vitro digestibility also varied significantly among the accessions (table 7). The two desert bitterbrush and the cliffrose were significantly more digestible than the others. Antelope bitterbrush from Lassen County, California, was more digestible than antelope bitterbrush from Colorado, Utah, or Idaho.

Table 7.--In vitro digestibility of winter forage samples from accessions of Apache-plume, antelope bitterbrush, desert bitterbrush, and cliffrose grown in a uniform garden. Data expressed on a dry matter basis

Accession	County and state	Digested dry matter (percent)
Purshia tridentata (Antelope bitterbrush)	Moffat, Colorado	24.1^{a*}
Purshia tridentata	Juab, Utah	25.2^{a}
Purshia tridentata	Carbon, Utah	26.4^{ab}
Purshia tridentata	Ada, Idaho	28.3^{ab}
Fallugia paradoxa (Apache-plume)	Sevier, Utah	29.8^{b}
Purshia tridentata	Lassen, California	30.6^{bc}
Purshia glandulosa (Desert bitterbrush)	Washington, Utah	34.6^{cd}
Purshia glandulosa	Mono, California	37.0^{d}
Cowania mexicana ssp. *stansburiana* (Cliffrose)	Utah, Utah	37.6^{d}

*Means sharing the same letter superscript are not significantly different at the 95 percent level.

The relationships between leafiness and crude protein and between leafiness and digestibility were highly significant (r=.80 and r=.92, respectively). Because these data were generated on even-aged plants grown in a uniform garden, we concluded that genetic factors play an important role in determining winter levels of leafiness, crude protein, and *in vitro* digestibility in antelope bitterbrush, desert bitterbrush, cliffrose, and Apache-plume. Due to the limited number of accessions we used, we are expanding our gardens to include more accessions of antelope bitterbrush, desert bitterbrush, and cliffrose. We hope to locate superior strains for our breeding and selecting program aimed at increasing the nutritional quality of bitterbrush planted on fall and winter ranges of mule deer and livestock.

PUBLICATIONS CITED

Alderfer, J. M. A taxonomic study of bitterbrush (*Purshia tridentata*) (Pursh) DC.) in Oregon. Corvallis, Oregon State University; 1976. 197 p. M.S. thesis.

Association of Official Analytical Chemists. Official methods of analysis. 13th ed. Washington, DC: Association of Official Analytical Chemists; 1980. 1018 p.

Bissell, H. D.; Harris, B.; Strong, H.; James, F. The digestibility of certain natural and artificial food eaten by deer in California. California Fish and Game 41: 57-78; 1955.

Blauer, A. C.; Plummer, A. P.; McArthur, E. D.; Stevens, R.; Giunta, B. C. Characteristics and hybridization of important Intermountain shrubs. I. Rose family. Res. Pap. INT-169. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1975. 23 p.

Cook, C. W. Comparitive nutritive values of forbs, grasses, and shrubs. In: McKell, C. M.; Blaisdell, J. P.; Goodin, J. R., eds. Wildland shrubs--their biology and utilization: proceedings of a symposium; July 1971; Logan, UT: Gen. Tech. Rep. INT-1. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1972: 303-310.

Dietz, D. R. Definition and components of forage quality. In: Paulson, H. A.; Reid, E. H.; Parker, K. W., eds. Range and wildlife habitat evaluation--a range symposium: proceedings of symposium; May 1968; Flagstaff and Tempe, AZ. Publ. 1147. Washington, DC: U.S. Department of Agriculture, Forest Service; 1970: 1-9.

Dietz, D. R. Nutritive value of shrubs. In: McKell, C. M.; Blaisdell, J. P.; Goodin, J. R., eds. Wildland shrubs--their biology and utilization: proceedings of a symposium; July 1971; Logan, UT. Gen. Tech. Rep. INT-1. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1972: 289-302.

Dietz, D. R.; Udall, R. H.; Yeager, L. E. Chemical composition and digestibility by mule deer of selected forage species, Cache La Poudre Range, Colorado. Tech. Publ. 14. Denver, CO: Colorado Fish and Game Department; 1962. 89 p.

Ensminger, M. E.; Olentine, C. G. Feeds and nutrition--abridged. Clovis, CA: The Ensminger Publication Company; 1978. 824 p.

Giunta, B. C.; Stevens, R.; Jorgensen, K. R.; Plummer, A. P. Antelope bitterbrush--an important wildland shrub. Publ. 78-12. Salt Lake City, UT: Utah State Division of Wildlife Resources; 1978. 47 p.

Koehler, D. L.; Smith, D. M. Hybridization between *Cowania mexicana* var. *stansburiana* and *Purshia glandulosa*. Madrono. 28: 13-25; 1981.

Kufeld, R. C.; Stevens, M.; Bowden, D. C. Winter variation in nutrient and fiber content and *in vitro* digestibility of Gambel oak (*Quercus gambelii*) and big sagebrush (*Artemisia tridentata*) from diversified sites in Colorado. J. Range Manage. 34: 149-151; 1981.

Leach, H. R. Food habits of the Great Basin deer herds of California. California Fish and Game. 42: 243-308; 1956.

Maynard, L. A.; Loosli, J. K.; Hintz, H. F.; Warner, R. G. Animal nutrition. 7th ed. New York: McGraw-Hill; 1979. 602 p.

Medin, D. E.; Anderson, A. E. Modeling the dynamics of a Colorado mule deer population. Wildl. Monogr. 68. Washington, DC: The Wildlife Society; 1979. 77 p.

National Academy of Sciences. Composition of cereal grains and forages. Publ. 585. Washington, DC: National Research Council; 1958. 663 p.

National Academy of Sciences. Nutrient requirements of domestic animals. No. 5. Nutrient requirements of sheep, Publ. 1193. Washington, DC: National Research Council; 1964. 36 p.

National Academy of Sciences. Nutrient requirements of domestic animals. No. 5. Nutrient requirements of sheep. 5th ed. Washington, DC: National Research Council; 1975. 72 p.

Pearson, H. A. Digestibility trials: in vitro techniques. In: Paulson, H. A.; Reid, E. H.; Parker, K. W., eds. Range and wildlife habitat evaluation--a range symposium: May 1968; Flagstaff and Tempe, AZ. Publ. 1147. Washington, DC: U.S. Department of Agriculture, Forest Service; 1970: 85-92.

Plummer, A. P.; Monsen, S. B.; Stevens, R. Intermountain range plant names and symbols. Gen. Tech. Rep. INT-30. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1977. 92 p.

Sheehy, D. P. Relative palatability of seven Artemisia taxa to mule deer and sheep. Corvallis, OR: Oregon State University; 1975. 147 p. Thesis.

Short, H. L.; Blair, R. M.; Burkhart, L. Factors affecting nutritive values. In: McKell, C. M.; Blaisdell, J. P.; Goodin, J. R., eds. Wildland shrubs--their biology and utilization: proceedings of a symposium; July 1971; Logan, UT. Gen. Tech. Rep. INT-1. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1972: 311-318.

Smith, A. D. Sagebrush as winter feed for mule deer. J. Wildl. Manage. 14: 285-289; 1950.

Smith, A. D. Digestibility of some native forages for mule deer. J. Wildl. Manage. 16: 309-312; 1952.

Smith, A. D. Nutritive value of some browse plants in winter. J. Range Manage. 10: 162-164; 1957.

Snedecor, G. W.; Cochran, W. G. Statistical methods. Ames: The Iowa State University Press; 1967. 593 p.

Tueller, P. T. Food habits and nutrition of mule deer on Nevada ranges. Reno: Nevada Agricultural Experiment Station, University of Nevada; 1979. 104 p.

Trout, L. E.; Thiessen, J. L. Physical condition of range relationships of the Owyhee deer herd. Boise, ID: Idaho Fish and Game Department; 1973. 37 p. Job completion report.

Uresk, D. W.; Messner, H. E. Constituents in in vitro solution contribute differently to dry matter digestibility of deer food species. J. Range Manage. 28: 419-421; 1975.

Urness, P. J.; Smith, A. D.; Watkins, R. K. Comparison of in vivo and in vitro dry matter digestibility of mule deer forages. J. Range Manage. 30: 119-121; 1977.

Wallmo, O. C.; Carpenter, L. H.; Regelin, W. L.; Gill, R. B.; Baker, D. L. Evaluation of deer habitat on a nutritional basis. J. Range Manage. 30: 122-127; 1977.

Ward, A. L. In vitro digestibility of elk winter forage in southern Wyoming. J. Wildl. Manage. 35: 681-688; 1971.

Welch, B. L. Nutritive value of big sagebrush and other shrubs. In: Stetler, L. H.; DePuit, E. J.; Mikol, S. A., eds. Shrub establishment on disturbed arid and semiarid lands: proceedings of symposium; 1980 December 2-3; Laramie, WY. Cheyenne, WY: Wyoming Game and Fish Department; 1981: 9-22.

Welch, B. L.; Andrus, D. Rose hips--a possible high-energy food for wintering mule deer? Res. Note INT-221. Ogden, UT: U.S. Department of Agriculure, Forest Service, Intermountain Forest and Range Experiment Station; 1977. 6 p.

Welch, B. L.; McArthur, E. D. Variation in winter levels of crude protein among Artemisia tridentata subspecies grown in a uniform garden. J. Range Manage. 32: 467-469; 1979.

Welch, B. L.; Monsen, S. B. Winter crude protein among accessions of fourwing saltbush grown in a uniform garden. Great Basin Nat. 41: 343-346; 1981.

Welch, B. L.; Pederson, J. C. In vitro digestibility among accessions of big sagebrush by wild mule deer and its relationship to monoterpenoid content. J. Range Manage. 34: 497-500; 1981.

GOAT USE IN FALL INCREASES BITTERBRUSH BROWSE AND REDUCES SAGEBRUSH DENSITY[1]

Philip J. Urness and Charles H. Jensen[2]

ABSTRACT

Bitterbrush responded to heavy fall grazing (100 percent of CAG) by Spanish goats with significant increases in twig production, while twig growth of big sagebrush generally decreased on plants used more than 70 percent (23 percent of those plants died). Thus, impact grazing favored bitterbrush and weakened big sagebrush, a desired result on ranges where quantity of sagebrush exceeds the forage needs of wintering big game.

INTRODUCTION

Attention has been focused recently on using domestic ungulates at various seasons and stocking intensities to manage for planned vegetational mixes on western North American rangelands. Spring grazing by cattle (Smith and Doell 1968) and sheep (Jensen and others 1972; Urness 1982) was compatible with winter use by deer and elk on Utah foothill ranges, provided domestic animals were removed before appreciable bitterbrush (Purshia tridentata Pursh [DC]) twig growth. Neal (1982) demonstrated similar responses of bitterbrush to early summer cattle use in northeastern California and south-central Oregon. Horses can be grazed on such ranges throughout summer without adverse impacts on bitterbrush or associated shrubs (Reiner and Urness 1982). Indeed, bitterbrush twig production can be increased by properly timed livestock grazing (Hubbard and Sanderson 1961). Anderson and Scherzinger (1975) reported a substantial increase in elk-carrying capacity on eastern Oregon rangeland where cattle were well managed. The unifying concept in these studies is that temporal separation allows livestock to utilize herbaceous forages that enhance the competitive capabilities of desirable shrubs, and/or improve the quality of herbaceous forage remaining for wintering big game.

Spanish goats have been used in the Southwest to decrease woody plants in pastures where interspecific competition and selective grazing have reduced more palatable forages (Huss 1972). Secondary benefits included lowered fuel loading (and risk of wildfire, Green and others 1979) and a marketable product--meat (Merril and Taylor 1976). Spanish goats were considered superior to other types for brush control; moreover, the authors indicated goats were productive on forage that sheep and cattle have difficulty utilizing.

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In Colorado, Gambel oak (Quercus gambelii Nutt.) sprouts were controlled by goats, and their use provided increased herbaceous forage for cattle (Davis and others 1975). High tannin levels in Gambel oak may limit the ability of goats to consume a monospecific diet (Nastis and Malechek 1981); however, when mixed with other nutritious forages, goats can perform well. This pattern likely occurs with other woody plants besides oaks. For example, goats were used to prune blackbrush (Coleogyne ramosissima Torr.) in winter to stimulate current season's growth and improve the quantity and quality of forage for cattle (Provenza and others[3]). Plants browsed heavily for four successive years produced significantly more current annual twig growth than unbrowsed plants. But high tannin content of current growth limited its palatability to goats and cattle (Provenza and Malechek[4]).

Thus, the literature indicates a highly specific response of different plant species to grazing, and the possibility that controlled grazing by different ungulates can accomplish certain range management goals. We have observed at several locations in Utah that some heavily used big game winter ranges supported well-developed stands of bitterbrush or cliffrose (Cowania mexicana D. Don). Other apparently similar sites that received light impacts by big game were dominated by big sagebrush (Artemisia tridentata Nutt.). Such vegetal patterns have variously been attributed to edaphic differences, but we hypothesized that the driving force in many cases was long-term differential use of more palatable associated shrubs favoring big sagebrush.

Conversely, if selective grazing by livestock or big game could be temporarily eliminated, a manager might develop a more desirable mix of palatable shrubs via impact use on big sagebrush. The latter species appears to have evolved chemical defenses against herbivory at the expense of grazing tolerance, in contrast to many shrubs in the family Rosaceae (bitterbrush and cliffrose included). This study, consequently, examined response of bitterbrush and big sagebrush to fall goat use at extremely heavy intensity to determine if such impacts could overcome the usual aversion of goats to big sagebrush (Narjisse 1981) to reduce its vigor and, perhaps, induce mortality.

STUDY AREA

In 1979 a 1.5-acre (0.6-ha) pasture was established in a big sagebrush-grass type about 4 mi (7 km) north of Hardware Ranch, Cache County, Utah. Vegetation was dominated by mountain big sagebrush (Artemisia tridentata ssp. vaseyana [Rydb.] Beetle), which accounted for nearly half of the total production (157 of 328 lb/acre; 176 of 368 kg per ha) and 80 percent of total shrub production. Green rabbitbrush (Chrysothamnus viscidiflorus [Hook.] Nutt.) was the second most abundant shrub. While bitterbrush was a common community component, it was not productive of current-annual-growth twigs (about 8 lb per acre; 9 kg/ha). All other shrubs combined yielded less than 2 percent of total production; of these, snowberry (Symphoricarpos oreophilus Gray) was most abundant.

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[3] Provenza, F. D.; Bowns, J. E.; Urness, P. J.; Malechek, J. C.; Butcher, J. E. Biological manipulation of blackbrush by goat browsing; 1983. In press.

[4] Provenza, F. D.; Malechek, J. C. Diet selection by domestic goats in relation to blackbrush twig chemistry; 1983. In press.

Herbaceous plants comprised about 40 percent of fall forage, but that did not account for the amount consumed by cattle in spring and early summer. Common grasses were beardless bluebunch wheatgrass (Agropyron inerme [Scribn. & Smith] Rydb.), bluegrasses (Poa spp. L.), and Letterman needlegrass (Stipa lettermanii Vasey). Common forbs were Louisiana sage (Artemisia ludoviciana Nutt.), Pacific aster (Aster chilensis Nees), Fremont geranium (Geranium fremontii Torr. ex Gray), and mulesear wyethia (Wyethia amplexicaulis [Nutt.] Nutt.). Forbs were generally available as standing dead material by late fall due to heavy frosts.

Soils are the Goering and Yeats Hollow series of silt loams with moderate stoniness. Topography is moderately sloping toward the southwest. Precipitation at Hardware Ranch averages about 16 inches (400 mm); winters are usually cold and dry but snow depths at the study pasture often preclude midwinter use by elk or deer. Summers are warm and dry. The frost-free period is short (mid-June to mid-September), but frost can occur in every month.

METHODS

We established a grid with 40 equally spaced intersects in the square study pasture, and a buffer zone was maintained around the fenced boundary. A stake was driven at each intersect, and one major outer branch on the bitterbrush and big sagebrush plants nearest each stake was permanently marked with a numbered metal tag. Lengths of all current annual twigs on these branches were measured in fall 1979 and 1980 and residual lengths of those twigs were remeasured in spring 1980 (Smith and Urness 1962). The same procedure was followed for a control pasture, except 80 plants of each species were measured. Comparison of fall 1980 twig measurements on the goat-grazed pasture vs. the control reflected relative yield changes, while use was estimated by twig length differences between fall 1979 and spring 1980.

In summer 1980 heavy goat use had apparently stimulated numerous adventitious buds on older branches toward the axes of bitterbrush plants. A variation of the point-quadrat technique (Warren-Wilson 1960) was used to detect this response. We took 50 point-frame samples on as many plants in the goat-grazed and the control pastures. A frame consisted of a color-coded pole with a pin guide that could be adjusted to various heights. The pin was inclined at 32.5° from horizontal to sample within four vertical strata across a 20-inch (50-cm) column. The strata were 0-6.7, 6.7-20.1, 20.1-33.1, and 33.1-46.1 inches (0-17, 17-51, 51-84, and 84-117 cm) above ground level. These strata were used to determine where on the plant twig production occurred. All point contacts with bitterbrush were recorded as dead wood, old wood, bud clusters, or current growth twigs. Each twig contacted by the point was measured for length to provide a relative production estimate.

Stimulation of adventitious buds did not occur on big sagebrush. Therefore, twig length measurements on the tagged branches adequately estimated growth response on that species.

On October 8, 1979, we placed 83 Spanish goats (16 adult females, 23 yearlings, and 44 kids) in the pasture. Mean individual weights for the three age groups were 86.6 lb (39.4 kg), 57.9 lb (26.3 kg), and 33.5 lb (15.2 kg), respectively, at completion of the trial on October 30. Total weight of the lot was 4,183 lb (1 901 kg) and, based on 1,000 lb (454.5 kg) = 1 animal unit (AU), the intensity of use was 2.14 AUM/acre (5.29 AUM/ha). Goats were supplemented with 0.5 lb (0.23 kg) alfalfa hay per animal per day during the last 10 days of the trial to assure good animal condition for subsequent breeding experiments, thus weight responses were confounded and are not reported in this paper.

RESULTS

Utilization

Spanish goats exhibited a clear aversion to big sagebrush for the first 10 days, but readily consumed all grasses, forbs, and other shrubs. By the end of the 23-day trial little current-growth material remained on any plant species except big sagebrush (fig. 1). On the 10th day when most other forage was consumed, it appeared that goats would not eat any appreciable amount of sagebrush (similar phenomena have been observed with deer (Carpenter and others 1979). However, a storm deposited 13 inches (33 cm) of snow accompanied by unseasonally cold temperatures (min. averaged 21° F, 6° C, from October 21 to 30). After the storm, goats readily browsed some big sagebrush plants but ignored others, and by the end of the trial use averaged 44 percent (Welch and others 1981 reported mule deer responding in a like manner). Use of individual sagebrush plants ranged from 0 to 100 percent. About 40 percent of the marked plants were unused, another 20 percent were browsed between 1 and 70 percent, and 40 percent of the plants were used in excess of 70 percent.

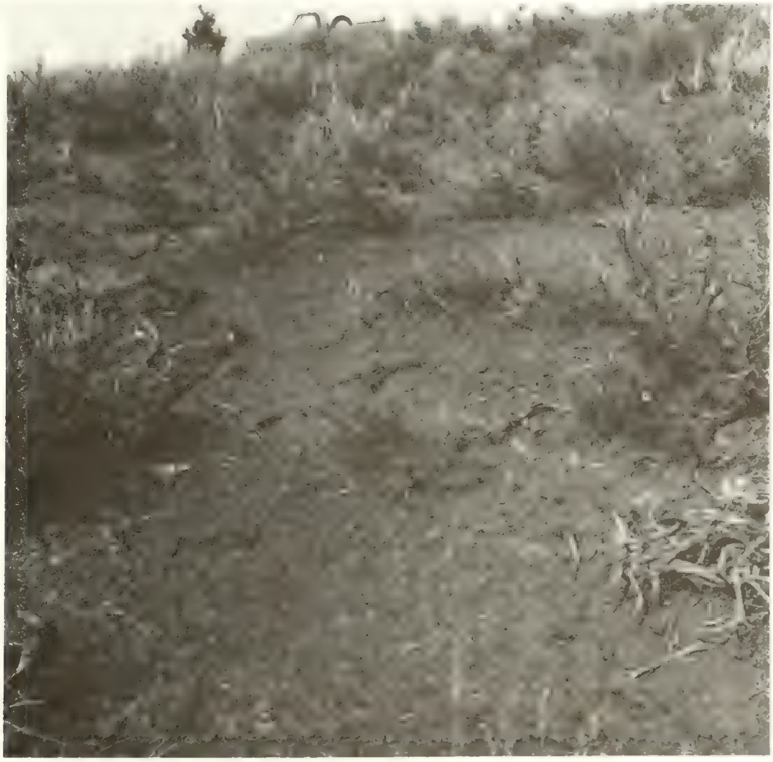


Figure 1.--Nearly complete use of available forage, including considerable litter, by goats in fall at Hardware Ranch. Only big sagebrush has current growth unused.

Bitterbrush use averaged 99.7 percent as determined by before-and-after-use measurements of current-growth twigs on peripheral branches. This was a conservative estimate, however, because a large quantity of older material was also consumed. Rarely have we observed such heavy use by other classes of ungulates; indeed, use was so extreme on some plants that even the bark was stripped from major branches (fig. 2).

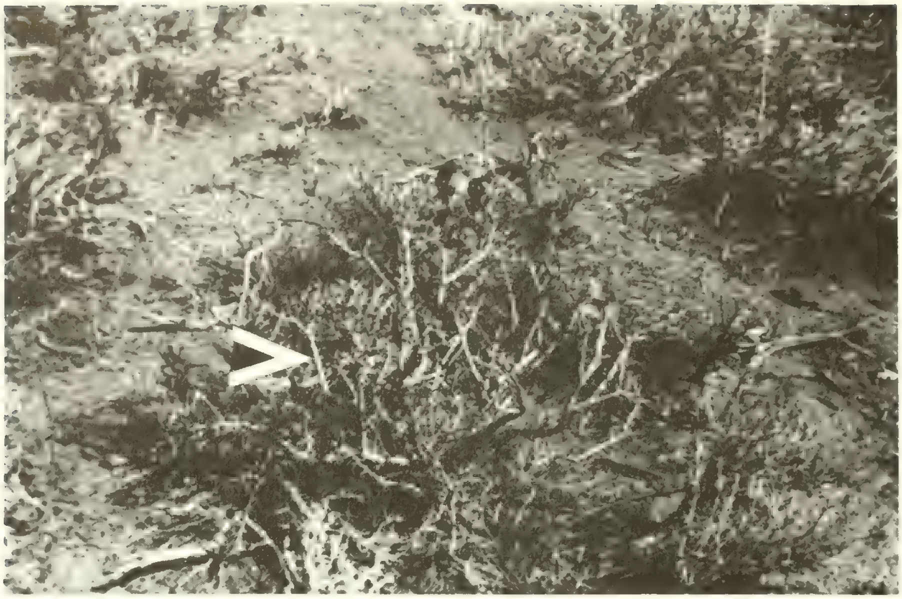


Figure 2.--Extreme use of bitterbrush including extensive bark stripping on older branches (arrows) by goats in fall at Hardware Ranch.

Subsequent Growth Responses

Big Sagebrush.--From 1979 to 1980, twig growth of big sagebrush decreased by 11 percent in the pasture grazed by goats and remained unchanged in the adjacent control pasture. Twig production on plants unused by goats increased 13 percent; it increased 35 percent on plants in the 1 to 70 percent use category. Twig growth decreased an average of 55 percent on plants used 70 percent or more (table 1).

Table 1.--Responses of big sagebrush plants to heavy fall grazing by Spanish goats at Hardware Ranch, Cache County, Utah

Use category	Mean utilization	1980 twig growth	Mortality
- - - - - - Percent	- - - - - -	Percent of 1979	Percent
0	0	113	0
1-70	40	135	0
71-100	91	45	23
Mean	44	89	10

These data indicate that utilization less than 70 percent was actually stimulatory to big sagebrush, but heavier use was harmful. Moreover, lightly used plants were more productive than unused ones. The decrease in production of plants used more than 70 percent was partly due to mortality. Also, about 25 percent of these plants increased in productivity despite heavy use.

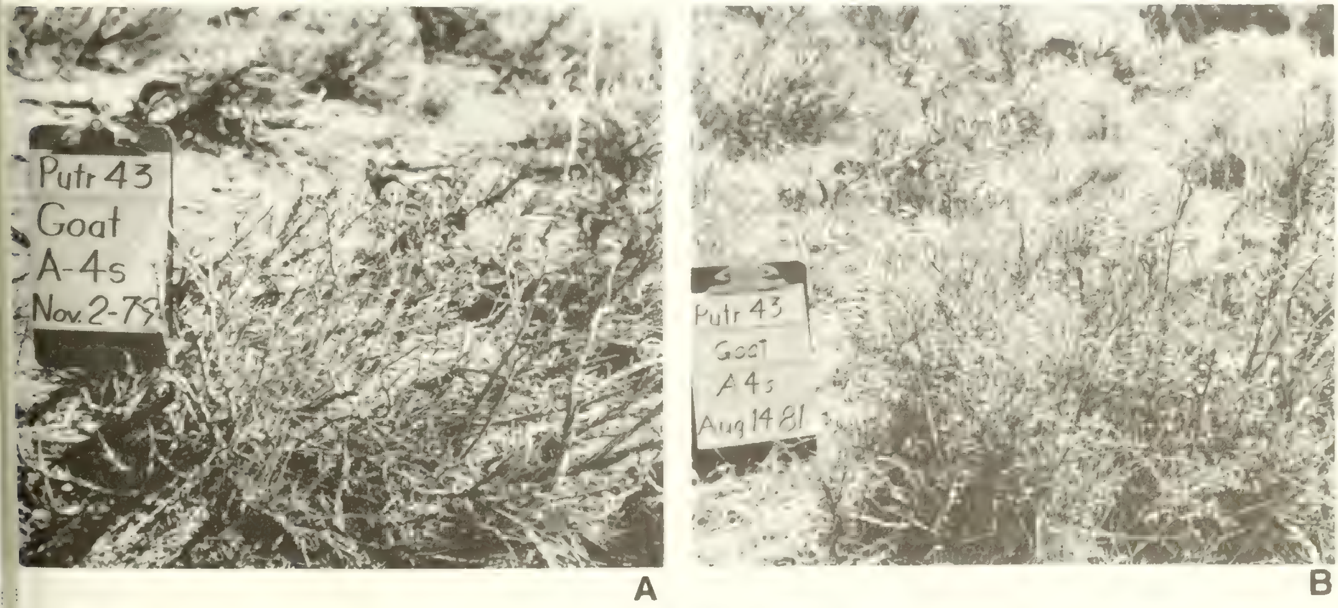
Bitterbrush.--The two techniques used to estimate growth response of bitterbrush yielded substantially different results. Twig length measurements of tagged peripheral branches showed an overall decrease in production (table 2). Buds decreased by 98 percent when compared to the controls; the number of twigs declined 91 percent and total twig length decreased 32 percent. However, average twig length was far greater, indicating a strong first-year, compensatory growth response.

Table 2.--Responses of bitterbrush plants to heavy browsing in fall 1979 by spanish goats at Hardware Ranch, Cache County, Utah, as determined by twig length measurements on peripheral branches in 1980.

	A	B	
Measured characteristic	Control plants	Goat-browsed plants	Percent B:A
Percent Utilization, 1979	0	99.7	--
Number of buds, 1980	5,699	111	2
Number of twigs, 1980	1,228	111	9
Total twig length, 1980	3,558 inches (9 087 cm)	2,435 inches (6 172 cm)	68
Average twig length, 1980	2.91 inches (7.4 cm)	21.9 inches (55.6 cm)	751

Very heavy browsing obviously reduced production of peripheral branches, but that is an incomplete picture. Another difference was the absence of seed on the heavily used plants. For example, 1,228 of the 5,699 buds on the control plants initiated twigs in 1980; nearly 80 percent of all buds did not and can be assumed to be flower buds. In contrast, all 111 buds of heavily browsed plants produced twigs.

Twig length data did not accurately reflect bitterbrush response as illustrated by data from the inclined-point technique. Most adventitious buds arose on older branches near basal axes, not on younger peripheral branches (fig. 3). However, due to increased twig length, some twigs originating from adventitious buds extended well into the peripheral branches of heavily browsed plants. Twig production on these plants as determined by point-contact sampling increased 719 percent relative to control plants (table 3). Moreover, twig growth resulting from stimulation of adventitious buds was substantially greater in all strata following heavy goat use. Thus, twig production was significantly increased, a result consistent with that obtained by artificial pruning (Ferguson and Basile 1966).



igure 3.--(A) Heavily used bitterbrush plant immediately after goats were removed from the pasture at Hardware Ranch. (B) The same plant two growing seasons after goat use showing excellent rejuvenation from basal adventitious buds.

Table 3.--Responses of bitterbrush to heavy fall (1979) browsing by Spanish goats at Hardware Ranch, Cache County, Utah, as determined from inclined-point-contact sampling in 1980

Measured characteristic	A Control plants	B Goat-browsed plants	Percent B:A/100
	Total point contacts per 50 frames		
Old wood	32	18	56
Dead wood	17	34	200
Bud clusters	26	0	--
Number of twigs	38	70	184
	Inches (cm)	Inches (cm)	
Total lengths of contacted twigs per stratum			
0-17 cm	14 (36)	53 (135)	375
17-51 cm	116 (295)	774 (1 967)	667
51-84 cm	37 (94)	334 (875)	931
84-117 cm	0 (0)	31 (79)	--
Total	167 (425)	1,202 (3 056)	719

Point-contact sampling further revealed an increase in dead wood, a decrease in old wood, an absence of buds (except basal adventitious buds), and an overall increase in twig numbers for browsed shrubs. In our opinion, this comprehensive analysis of the entire plant is a more valid characterization of effective responses of bitterbrush to goat browsing.

Goats used all other plant species heavily, but their responses were confounded somewhat with spring grazing by cattle in 1979. Utilization in 1979 was estimated to be 73 percent on grasses, 45 percent on forbs, and 5 percent on shrubs. Big sagebrush received no use and bitterbrush use averaged 2 percent. Deer and elk use from late fall to early spring was also light because of research activity during fall and deep snow in winter. Cattle did not use the area in 1980. Therefore, the response of shrubs is attributed primarily to browsing pressure imposed by the goats.

DISCUSSION

An overwhelmingly conservative attitude has existed among range managers regarding allowable use levels on plants. Such concepts as "take half, leave half" or "60 percent use of key species is maximal" are perpetuated despite strong evidence that such practices, rigidly applied, are not always best. In fact, such concepts often allow selective grazing by herbivores of the more palatable species to a result opposite that of stated management goals; namely, an increase in less palatable competitive species such as big sagebrush. In grazing intensity-plant competition interactions, a number of factors are operative that ultimately have a strong bearing on the type of plant community that will develop.

In this study we were interested in the relative competitive advantage big sagebrush (low palatability) has over bitterbrush (high palatability) in traditional grazing systems. More specifically, whether a dramatic shift in grazing pattern both in terms of intensity (very heavy) and timing (fall, when physiological activity of both shrubs is minimal) could alter this competitive interaction to favor bitterbrush. Our data support a contention that temporary heavy use accomplished this purpose despite the fact that utilization of bitterbrush averaged twice that of big sagebrush. Further, earlier data indicated that bitterbrush can become more and sagebrush less prominent in the stand provided sufficient grazing pressure is imposed on other vegetational components in spring and early summer (Jensen and others 1972; Reiner and Urness 1982). Most likely a combination of growing-season and fall use will be necessary to significantly increase bitterbrush and decrease sagebrush dominance.

The selective use of big sagebrush at usually low overall grazing intensities presents still another problem. Since certain individual sagebrush plants are more palatable than others, they consistently sustain much higher use levels than less palatable ones, which likely leads to loss of the better plants over time. Certainly, mortality of 23 percent of the more palatable individuals in this study represents a potential trend. However, not all heavily used sagebrush plants decreased in production, indicating that some individuals possess greater resistance to browsing than others. To avoid or reduce selective grazing and the competitive advantage such a process conveys to less palatable plants, sufficiently heavy use must be imposed, at least periodically, to impact the entire population.

A short-term, high-intensity approach (Savory 1978; Heitschmidt and others 1982) might possibly achieve the desired result, yet our study confined large numbers of goats in a small area but failed to impose uniform use on big sagebrush, even with supplementation. It appears that any similar effort would require close confinement, supplemental feeding, and a longer time frame to be effective. Obviously the application of such an approach to a herd unit or grazing allotment is very limited.

PUBLICATIONS CITED

Anderson, E. W.; Scherzinger, R. J. Improving quality of winter forage for elk by cattle grazing. J. Range Manage. 28: 120-125; 1975.

Carpenter, L. H.; Wallmo, O. C.; Gill, R. B. Forage diversity and dietary selection by wintering mule deer. J. Range Manage. 32: 226-229; 1979.

Davis, G. G.; Bartel, L. E.; Cook, C. W. Control of Gambel oak sprouts by goats. J. Range Manage. 28: 216-218; 1975.

Ferguson, R. B.; Basil, J. V. Topping stimulates bitterbrush twig growth. J. Wildl. Manage. 30: 839-841; 1966.

Green, L. R.; Hughes, C. L.; Graves, W. L. Goat control of brush regrowth on southern California fuelbreaks. Rangelands. 1: 117-119; 1979.

Heitschmidt, R. K.; Price, D. L.; Gordon, R. A.; Frasure, J. R. Short duration grazing at the Texas Experimental Ranch: effects on aboveground net primary production and seasonal growth dynamics. J. Range Manage. 35: 367-372; 1982.

Hubbard, R. J.; Sanderson, H. R. Herbage production and carrying capacity of bitterbrush. Res. Note PSW-157. Berkeley, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station; 1961. 6 p.

Huss, D. L. Goat response to use of shrubs as forage. In: McKell, C. M.; Blaisdell, J. P.; Goodin, J. R., eds. Wildland shrubs--their biology and utilization. Gen. Tech. Rep. INT-1. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1972: 331-342.

Jensen, C. H.; Smith, A. D.; Scotter, G. W. Guidelines for grazing sheep on rangelands used by big game in winter. J. Range Manage. 25: 346-352; 1972.

Merrill, L. B.; Taylor, C. A. Take note of the versatile goat. Rangeman's J. 3: 74-76; 1976.

Narjisse, H. Acceptibility of big sagebrush to sheep and goats: role of monoterpenes. Logan, UT: Utah State University; 1981. 124 p. Dissertation.

Nastis, A. S.; Malechek, J. C. Digestion and utilization of nutrients in oak browse by goats. J. Anim. Sci. 53: 283-290; 1981.

Neal, D. L. Improvement of Great Basin deer winter range with livestock grazing. In: Proceedings 10, Wildlife-livestock relationships symposium; 1981 April 20-22; Coeur d'Alene, ID. Moscow, ID: University of Idaho; 1982: 61-73.

Reiner, R. J.; Urness, P. J. Effects of grazing horses managed as manipulators of big game winter range. J. Range Manage 35: 567-571; 1982.

Savory, A. A holistic approach to ranch management using short duration grazing. In: Proceedings of the First International Rangelands Congress; 1978 August 14-18; Denver, CO: Society for Range Management; 1978: 555-557.

Smith, A. D.; Doell, D. D. Guides to allocating forage between cattle and big game on big game winter range. Publication 68-11. Salt Lake City, UT: Utah State Division of Fish and Game; 1968. 32 p.

Smith, A. D.; Urness, P. J. Analyses of the twig-length method of determining utilization of browse. Publ. 62-9. Salt Lake City, UT: Utah Game and Fish Department 1962. 34 p.

Urness, P. J. Livestock as tools for managing big game winter range in the Intermountain West. In: Proceedings, Wildlife-livestock relationships symposium; 1981 April 20-22; Couer d'Alene, ID. Moscow, ID: University of Idaho Forest, Wildlife and Range Experiment Station; 1982: 20-31.

Warren-Wilson, J. Inclined point quadrats. New Physiologist. 59: 1-8; 1960.

Welch, B. L.; McArthur, E. D.; Davis, J. N. Differential preference of wintering mule deer for accessions of big sagebrush and for black sagebrush. J. Range Manage. 34: 409-411; 1981.

DYNAMICS OF ANTELOPE BITTERBRUSH SEED CACHES[1]

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ABSTRACT

The natural regeneration of bitterbrush (Purshia tridentata [Pursh] DC.) is closely tied to the collection and seed caching activities of rodents. Predation by rodents and insects interfere with artificial vegetation of bitterbrush. Successful seeding of bitterbrush is dependent on understanding and adapting to the ecology of rodent populations.

INTRODUCTION

The perfect yellow flowers of antelope bitterbrush (Purshia tridentata [Pursh] DC.) are borne singly at the end of short, lateral, leafy spurs. The fruit is an achene about 0.13 to 0.5 inches (6 to 12 mm) long. The achene consists of the embryo comprised or radicle, hypocotyl, and cotyledons and is covered by the seedcoat and pericarp. The ovary wall or pericarp is fused to the actual seedcoat to form the achene. The achene is dry and flinty when mature, and we will refer to it as seed. When the seeds of antelope bitterbrush are mature, they fall from the plant with a papery covering composed of remnant flower parts tipped with a remnant of the style.

The papery covering of antelope bitterbrush seeds largely inhibits germination when the seeds are germinated in petri dishes (Hormay 1943). When the seeds are allowed to remain in the natural seedbed, presumably strict dormancy is imposed until this papery covering is rotted away (which probably occurs over winter). After overwintering the seeds can germinate. However, this is not usually the case in natural situations because almost the entire crop of antelope bitterbrush seeds is collected by rodents and Pogonomyrmex ants (Young and Evans 1978). When rodents collect bitterbrush seeds, they often remove the papery covering before caching 10 to 100 seeds in tight clusters buried about 2 inches (5 cm) deep in the soil (Hormay 1943). Apparently rodents discriminate among types of sites they use for caching. Accumulation of duff and litter discourages rodent caching activities (Sherman and Chilcote 1972). These caches remain in the soil over winter, and the seeds receive natural stratification (see Young and Evans this volume for details of stratification requirements). In the early spring, cotyledons of the germinating seeds form tight, rose-purple rosettes, identifying the cache locations. Rodents return to graze on the cotyledons which are rich in carotene which is often vital in the diet of the rodents in early spring (for examples of similar situations, see Beatley 1969 and La Tourrette and others 1971). If rodents failed to return and graze the seedlings, the seedlings would often die from intraspecific competition. Sloppy grazing by the rodents allows an occasional seedling to escape and possibly to become established. This highly complex regeneration system can be easily influenced by human activities but is hard to direct. Even if seedlings do escape rodent predation, other predators and diseases can cause mortality. Hubbard (1956) found varigated cutworm (*Peridroma saucia* [Hubmer]) damage on bitterbrush seedlings at the Doyle Experimental Area, Lassen County, California. Ninety percent of seedlings emerging in the spring of 1956 from seeds planted in the fall of 1955 were destroyed by worms. Nord (1965) described numerous insect species which are known to injure and destroy bitterbrush, including cutworms, tussock moth (*Orygyia vestusta* [Boisduval]), green plant bug (*Chlorochroa uhleri* [Stal]), and the Great Basin tent caterpillar (*Malacosoma californicum fragiles* [Stretch]). Also, several damping-off fungi (*Rhizoctonia solani* [Kuehn]), *Pythium ultimum* [Traus]) were shown to be pathogenic on bitterbrush seedlings.

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Our purpose was to investigate portions of the caching-regeneration system for antelope bitterbrush in order to more fully understand its functions. We believe that rodent grazing, insect feeding, fungal disease, and soil nutritional levels interact to greatly reduce seedling survival of antelope bitterbrush and that mortality caused by these factors in a function of density and depth of seed caching.

MATERIALS AND METHODS

Because of the impossibility of going to a given field location and automatically reproducing all portions of the antelope bitterbrush regeneration cycle, (seed production, rodent caching, and germination), experimental comparisons are more a function of opportunistic research. When we noticed the opportunity to experiment with the regeneration cycle we took advantage of the phenomenon. To bring balance to this necessarily disjunct approach we artificially reproduced portions of the cycle to establish meaningful experimental comparisons. All of these comparisons combine to create a rather complex experimental approach.

Studies of Natural Caches

In August 1980, about 16 ha of a mature stand of antelope bitterbrush burned in a wildfire located in Little Antelope Valley, Mono County, California. The stand constituted an important mule deer (*Odocoileus hemionus* [Rafinesque]) winter range and was situated on an alluvial fan just below the lower margin of the pinyon (*Pinus monophylla* Torr. and Frem.)/juniper (*Juniperus osteosperma* [Torr.] and *J. occidentalis* Hook. ssp. *australis* Vasek) woodlands of the eastern slope of the Sierra Nevadas. The soils were coarse-textured and derived from decomposing granite parent material. The wildfire was fast-moving and apparently very hot because stems of mountain big sagebrush (*Artemisia tridentata* Nutt. ssp. *vaseyana* [Rydberg] Beetle) burned to the soil level.

In the spring of 1981 many rodent caches of antelope bitterbrush seedlings were visible in the burned area. During early March we selected 100 seed caches in the burn and 20 in an adjacent unburned stand. The caches were randomly divided into groups of 20 and given the following treatments: (1) control caches in the burned area, (2) caches covered with rodent-proof caps made of 1 cm opening hardware cloth, (3) caches treated with 0.17 ounces (5 ml) of 0.03 percent solution of the insecticide diazinon, (4) caches treated with 0.17 ounces (5 ml) of 0.005 percent suspension of the fungicide benomyl, (5) caches treated with 0.17 ounces (5 ml) of

Studies of Artificial Caches

Field trials with artificial caches of antelope bitterbrush with variable numbers and depths of seeds were initiated in March 1982. Experiments were conducted at Doyle, Lassen County, California and Granite Peak, Washoe County, Nevada. Both sites are representative of the same type of plant community and soils found at Little Antelope Valley. Four replications in a randomized block design were used in all experiments. Seed caches were prepared in plastic boxes 4 x 4 x 3 inches (10 x 10 x 8 cm) with drainage holes. The boxes were filled with soil from the sites and compacted to comparable bulk densities. The seeds were placed on a fiberglass screen to facilitate recovery. Unless otherwise specified, antelope bitterbrush seeds collected at Lakeview, Oregon in 1981 were used. Depth treatments consisted of 100 seeds each planted: (1) on the surface, (2) at 0.4 inches (1 cm), (3) at 0.8 inches (2 cm), and (4) at 1.6 inches (4 cm) below the surface. Using deeper boxes in one trial at Doyle, the seeds were planted 10 cm deep.

In number of seeds-per-cache trials, seeds were planted at 0.4 inches (1 cm) depth with the number of seeds consisting of 1, 2, 5, 7, 10, 45, and 100 per box.

The boxes were carefully buried in the field according to the experimental design. Then the burial sites and surrounding area were raked and swept to blend in with the site. The boxes were recovered from the field after 1 week and the seeds were recovered by washing and screening the contents of the boxes.

Treatments testing olfactory sensitivity of rodents included caching at 1 cm in the soil 100 seeds of antelope bitterbrush with the papery flower parts attached. A second treatment consisted of caching at 0.4 inches (1 cm) 100 seeds that had been coated with two coats of plastic resin and baked dry. A third treatment consisted of finely grinding 100 antelope bitterbrush seeds and mixing the ground material with 100 seeds of crested wheatgrass (Agropyron desertorum, [Fisch.] Shult. cultivar 'Nordan'). This mixture and a treatment with 100 crested wheatgrass seeds, alone, were cached 1 cm deep.

To compare rodent preference for different sources of antelope bitterbrush we cached 100 seeds, 0.4 inches (1 cm) deep, from each of the sources collected in 1981: (1) Lakeview, Oregon, (2) Mono Lake, California (desert bitterbrush [Purshia glandulosa Curran]), (3) Chelan, Washington, (4) Tollgate, Idaho, and (5) Hotsprings, Montana. This experiment was repeated twice at Doyle; once in a randomized block with the boxes touching each other and once with the boxes randomly distributed in a 2.5 acre (1 ha) area.

Sherman live traps (baited with rolled oats) and rat-size snap traps (baited with rolled oats and peanut butter) were used on the study areas to determine rodent species present. Traps were set in lines of 10 stations, spaced 33 ft (10 m) apart, with one trap per station. Total trapping effort was 310 trap nights.

RESULTS

Natural Caching Studies

CHARACTERISTICS OF CACHES

In the area burned by wildfire in Little Antelope Valley, we found 3,600 rodent caches per acre (0.88 per m^2) of antelope bitterbrush seedlings in the spring of 1981. In the unburned area only 650 caches per acre (0.16 per m^2) were found. We attributed the lower number of caches in the unburned area to rodent predation during the winter. There were numerous small rodent excavations indicating where caches had been raided. In the burned area, probably because of lack of cover, these excavations were not found.

In the burned area, the average number of antelope bitterbrush seedlings per cache was 12.5 with a range of 7 to 31. At the cotyledon stage of emergence, 30 percent of the antelope bitterbrush seedlings that we recovered from caches had evidence of damage apparently caused by insects. The underside of the cotyledons had been eaten leaving only the cuticle of the upperside of the seed leaves.

In the soil on the burned area from which caches were excavated for counting, we found an average of 8 ungerminated antelope bitterbrush seeds per cache. Careful examination of the seeds revealed an average of only 1 seed per cache that was not obviously broken or empty. Incubation of the entire seeds at 59°F (15°C) failed to produce any germination.

CACHES AND TREATMENTS

When we monitored through spring and summer the undisturbed seedlings of antelope bitterbrush growing from rodent caches at Little Antelope Valley, we found that all the seedlings in the burned control had died by June 19 (table 1). In the unburned control the seedlings started growing 2 weeks later, apparently because of shading caused by large shrubs, but they were all dead by June 12.

There were several apparent reasons for seedling mortality in the populations in relation to treatment and time. The first week after emergence the caches lost an average of 38 percent of their seedlings regardless of treatment. This we attribute to the lack of frost hardiness of antelope bitterbrush seedlings (unpublished data, R. L. Everett, Intermountain Forest and Range Experiment Station, U.S. Forest Service, Reno, Nevada). Antelope bitterbrush seedlings in the unburned control suffered a similar level of mortality in the first week even though they emerged 2 weeks later.

Rodent damage to seedling was never a factor in the burned area; therefore, the cage treatment was ineffective (table 1). In the unburned control, rodent damage was severe. Also, in the unburned control, late spring growth of cheatgrass (Bromus tectorum) formed a dense stand and offered severe competition for available moisture (Evans and others 1970). The burned area was virtually free of cheatgrass.

The addition of a complete nutrient solution to the caches hastened death of seedlings with all being dead by May 7 (table 1). Added nutrients may have increased moisture stress before the seedlings were deeply enough rooted to extract from the receding level of available water in the soil. The fungicide treatment did not markedly change the rate or date of total seedling death.

From March 17 to April 16, seedlings in the insecticide treatment had a mortality pattern similar to that observed in the burned control (table 1). After April 16, the rate of mortality in the insecticide-treated caches slowed and leveled off with 46 percent of the original seedling density surviving the summer. These seedlings reached the third true leaf stage by the end of the summer. By the spirng of 1982 some antelope bitterbrush plants had become established in all of the insecticide-treated caches. We made an extensive collection of insects at the site, but entomologists did not consider any of the insects we collected as responsible for the type of seedling damage observed. In earlier studies, Hubbard (1956) found that wireworms destroyed bitterbrush seedlings.

Table 1.--Percent survival of antelope bitterbrush seedlings in rodent caches as related to date (March through July) and various treatments. Experiment conducted in Little Antelope Valley, Mono County, California[a]

	Percent survival					
	Unburned area	Burned area				
Date	Control	Control	Insecticide (diazinon)[b]	Fungicide (benomyl)[c]	Cages	Nutrient solutions[d]
March 17	--	100	100	100	100	100
24	--	60	69	68	59	56
31	100	40	56	60	27	43
April 14	70	38	51	59	12	12
16	50	34	50	27	7	6
21	37	14	44	17	5	1
May 7	21	13	46	12	4	0
21	10	9	46	9	2	0
June 3	2	7	46	4	1	0
12	0	2	46	0	0	0
19	0	0	46	0	0	0
July 6	0	0	46	0	0	0

[a] Not all treatments were started on the same date. The unburned control was delayed 2 weeks because the seeds germinated slower and seedlings emerged later in the heavy shade of the large shrubs.

[b] 0.03 percent solution of diazinon.

[c] 0.005 percent solution of benomyl.

[d] 0.03 percent solution of 12-6-8 nutrient solution.

Artificial Caching Studies

A hard freeze in June 1981 destroyed much of the antelope bitterbrush seed crop on the eastern slope of the Sierra Nevadas, making it impossible to get a second year of data concerning natural caching. Using a different tact on the same general problem we artificially distributed caches of antelope bitterbrush seeds during the time when rodents were voraciously destroying the few natural caches that were germinating.

NUMBER OF SEEDS PER CACHE

When only one antelope bitterbrush seed was cached 0.4 inches (1 cm) deep, the rodents never bothered to dig it up at either location, even though the box containing the single seed was buried in an experimental design with other boxes that contained as many as 100 seeds (table 2). If two seeds were cached, rodents removed 75 percent of the seeds at both locations. At Doyle, if caches were composed of 10, 45, or 100 seeds, the rodents removed at least 98 percent of the seeds. Reichman and Oberstein (1977) showed that size (and depth) of seed caches affected their detection by rodents. Predation was not as high at Granite Peak, possibly because it is a higher and colder location than Doyle with less rodent activity at the same date.

Table 2.--Rodent predation of antelope bitterbrush seeds placed in artificial caches with different numbers of seeds per cache. Experiment conducted at Doyle, California and Granite Peak, Nevada. Seeds cached 0.4 inches (1 cm deep).

	Percent predation by rodents	
Number of seeds per cache	Doyle	Granite Peak
1	0	0
2	75	75
5	90	84
7	93	82
10	99	80
45	98	54
100	98	66

DEPTH OF BURIAL

At Doyle, rodents removed all of the antelope bitterbrush seeds cached on the soil surface (table 3). Only 8 percent of the seeds were recovered from burial at 1.6 inches (4 cm) after being exposed to rodent predation. At Granite Peak, predation was severe on the surface and at 0.4 inches (1 cm), but dropped to 50 and 47 percent at 0.8 and 1.6 inches (2 and 4 cm) burial, respectively. At Doyle, we also buried antelope bitterbrush seed 4 inches (10 cm) deep in special boxes. The rodents did not disturb these seeds. Because seeds are discovered by rodents primarily via olfactory cues (Howard and Cole 1967; Johnson and Jorgensen 1981), the low discovery rate of deeper caches is not surprising. Differences in rates of discovery between the two sites may be caused by a variety of factors including rodent species involved, soil moisture, etc. (Johnson and Jorgensen 1981).

Table 3.--Rodent predation in relation to depth of burial of antelope bitterbrush seeds. 100 seeds placed in all caches. Experiment conducted at Doyle, California and Granite Peak, Nevada

	Percent predation by rodents	
Depth of burial	Doyle	Granite Peak
Surface	100	91
0.4 inches (1 cm)	98	95
0.8 inches (2 cm)	99	50
1.6 inches (4 cm)	92	47

OTHER TREATMENTS

Leaving the papery bracts on the antelope bitterbrush seeds had no influence on subsequent predation of cached seeds. Likewise, coating the seeds with a plastic residue before caching them 0.4 inches (1 cm) deep did not markedly limit predation.

Rodents did not disturb caches of 100 seeds of crested wheatgrass. However, when the crested wheatgrass seeds were mixed with 100 finely ground antelope bitterbrush seeds before caching, the rodents completely excavated the boxes and chewed into small pieces the fiberglass screens that were placed below the seeds to aid in recovery.

SOURCES OF SEED

The five sources of bitterbrush seed that we tested, including one source of desert bitterbrush, appeared to be equally susceptible to predation by rodents (table 4). Where all the boxes of seeds were put together in an experimental design, this might be construed as baiting the rodents. Predation, however, appeared to be just as severe whether seeds were cached at random locations or in an area where the boxes were located adjacent to each other.

Table 4.--Rodent predation in relation to seed sources of antelope and desert bitterbrush. 100 seeds cached 0.4 inches (1 cm) deep. Seeds of different sources were placed in boxes that were both close together and widely spaced. Experiment was conducted at Doyle, California.

	Percent predation by rodents	
Seed source	Adjacent	Remote
Lakeview, Oregon	95	100
Mono Lake, California[a]	100	99
Chelau, Washington	100	100
Tollgate, Idaho	100	100
Hotsprings, Montana	99	97

[a] Desert bitterbrush

Rodent Predators

The species of rodents we captured in these communities were: deer mice (Peromyscus maniculatus), Great Basin pocket mice (Perognathus parvus), least chipmunks (Eutamias minimus), and Panamint kangaroo rats (Dipodomys panamintinus). Gustafson (1974) trapped intensively (approximately 7200 trap-nights) in a plant community similar to those we trapped and located very near our Granite Peak site. He recorded the presence of other seed-eating rodents, including Ord's kangaroo rat (D. ordii), Great Basin kangaroo rats (D. microps), and dark kangaroo mice (Microdipodops megacephalus). According to Everett and others (1978), bitterbrush seeds are a highly preferred food source of deer mice, a rodent species credited with being the major consumer of artificially planted seed (Nelson and others 1970).

DISCUSSION

The collecting, caching, germination, and subsequent grazing of antelope bitterbrush seeds and seedlings form a very complex regeneration process. A similar process has been described for other plant species (Reynolds 1950; La Tourrette and others 1971; McAdoo and others 1983). This study points out the varied types of perturbations that are involved in the seedling establishment process. In designing a management program to enhance regeneration of antelope bitterbrush, managers and researchers must be cognizant of interacting effects of rodent activities and plant competition. In any plan they design for seeding antelope bitterbrush seeds in an artificial regeneration scheme, they must also recognize the great potential for seed predation by rodents. The depths at which seeds are typically planted in reseeding attempts 0.2 to 0.5 inches (0.5 to 1.3 cm) are ideal for discovery of seeds by rodents (Johnson and Jorgensen 1981). Also, the possible role of insect predation on antelope bitterbrush seedlings certainly deserves additional research.

PUBLICATIONS CITED

Beatley, J. D. Dependence of desert rodents on winter annuals and precipitation. Ecology 50: 721-724; 1969.

Evans, R. A.; Holbo, H. R.; Eckert, R. E., Jr.; Young, J. A. Functional environment of downy brome communities in relation to weed control and revegetation. Weed Science 18: 154-162; 1970.

Evans, R. A.; Young, J. A. Bitterbrush germination with constant and alternating temperatures. J. Range Manage. 30: 30-32; 1977.

Everett, R. L.; Meeuwig, R. O.; Stevens, R. Deer mouse preference for seed of commonly planted species, indigenous weed seed, and sacrifice foods. J. Range Manage. 31: 70-73; 1979.

Gustafson, J. R. Vertebrate structure of a sagebrush community. Washoe County, Nevada. Reno, NV: University of Nevada; 1974. 268 p. Dissertation.

Hormay, A. L. Bitterbrush in California. Res. Note No. 9. Berkeley, CA: U.S. Department of Agriculture, Forest Service, California Forest and Range Experiment Station; 1943. 13 p.

Howard, W. E.; Cole, R. E. Olfaction in seed detection by deer mice. J. Mammalogy 48: 147-150; 1967.

Hubbard, R. L. Bitterbrush seedlings destroyed by cutworms and wireworms. RES. Note. Berkeley, CA: U.S. Department of Agriculture, Forest Service, California Forest and Range Experiment Station; 1956. 114 p.

Johnson, T. K.; Jorgensen, C. D. Ability of desert rodents to find buried seeds. J. Range Manage. 34: 312-314; 1981.

La Tourrette, J. E.; Young, J. A.; Evans, R. A. Seed dispersal in relation to rodent activities in seral big sagebrush communities. J. Range Manage. 24: 118-120; 1971.

McAdoo, J. K; Evans, C. C.; Roundy, B. A.; Young, J. A.; Evans, R. A. Influence of heteromyid rodents on Oryzopsis hymenoides germination. J. Range Manage.; 1983.

Nelson, J. R.; Wilson, A. M.; Goebel, C. J. Factors influencing broadcast seeding in bunchgrass range. J. Range Manage. 23: 163-170; 1970.

Nord, E. C. Autecology of bitterbrush in California. Ecological Monogr. 35: 307-334; 1965.

Reichman, O. J.; Oberstein, D. Selection of seed distribution types of Dipodomys merriami and Perognathus amplus. Ecology 58: 636-643; 1977.

Reynolds, H. G. Relation of Merriam kangaroo rats to range vegetation in southern Arizona. Ecology 31: 456-463; 1950.

Sherman, R. J.; Chilcote, W. W. Spatial and chronological patterns of Purshia tridentata as influenced by Pinus ponderosa. Ecology 53: 294-298; 1972.

Young, J. A.; Evans, R. A. Germination requirements as determinants of species composition of Artemisia rangeland communities. Proc. First International Rangelands Congress. Denver, CO: Society for Range Management. 1978: 366-369.

SUMMER USE OF BITTERBRUSH RANGELANDS BY MULE DEER[1]

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ABSTRACT

Tractable mule deer were used to determine diet composition on summer rangeland characterized by bitterbrush, big sagebrush, and Utah juniper. Diets, composed mostly of forbs in spring, steadily shifted to bitterbrush dominance, reaching 91 percent in September. Based on available forage and percent dietary crude protein, the plant community was determined adequate for supporting mule deer. Management recommendations are discussed.

INTRODUCTION

The forage value of antelope bitterbrush (Purshia tridentata [Pursh] DC.)[3] to Rocky Mountain mule deer (Odocoileus hemionus Refinesque) has been well documented (Kufeld and others 1973). While most research dealt with use on winter ranges, the summer use of antelope bitterbrush appears to be important on ranges where high quality forages are limited.

In 1976 the Utah Division of Wildlife Resources identified 29 of 74 deer management units in which summer ranges were considered equal or more limiting in forage resources than the associated winter ranges (Hancock and others 1976). These units cover the western third and southeastern quarter of Utah, with similar ranges extending into portions of Nevada, Idaho, Colorado, and Arizona. Because they have lower precipitation and warmer temperatures than typical high elevation summer ranges, these units contain vegetal communities that are usually considered spring-fall or winter range types. They are characterized by plant communities containing curlleaf mahogany (Cercocarpus ledifolius Nutt.), Gambel oak (Quercus gambelii Nutt.), big sagebrush (Artemisia tridentata Nutt.), low sagebrush (Artemisia tridentata arbuscula [Nutt.] H.&C.), Utah serviceberry (Amelanchier utahensis Nutt.), and mountain snowberry (Symphoricarpos oreophilus Gray). Only limited acreages of high quality summer range, such as communities containing quaking aspen (Populus tremuloides Michx.), conifer, riparian, or upland meadows, are available, and consequently deer are forced to select less than optimal vegetal types. Nonetheless, these units have contributed a significant proportion (21 percent in 1981) to the total Utah deer harvest.

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[3] Scientific names are from Harrington, H. D. Manual of the plants of Colorado, Swallow Press, Inc., Chicago, Ill,; 1964, 666 pp. and Welsh, S. L., Moore, G. Utah plants, 3rd edition, Brigham Young Univ. Press, Provo, Utah.

Areas containing antelope bitterbrush are usually not considered summer range, especially where associated with pinyon-juniper (Olson and Logan 1973), yet many deer occupy these ranges throughout the summer. Consequently, the intent of this research was to investigate the adequacy of such ranges to support summering mule deer.

AREA AND METHODS

The study area was located in west-central Utah on the north slope of Sabie Mountain, which is part of the West Tintic Range. The elevation is 6,460 ft (1 970 m) and yearly precipitation averages about 9 inches (24 cm), received primarily during winter. Antelope bitterbrush occurs at varying densities within a singleleaf pine (*Pinus monophylla* Torr. & Frem.)-Utah juniper (*Juniperus osteosperma* Torr.) stand that dominates a zone extending from about 5,900 to 6,900 ft (1 800 to 2 100 m). Above and below the pinyon-juniper zone are treeless ranges dominated by big sagebrush. Althoug usually grazed in summer by cattle, no use occurred during the sampling period.

Mule deer diets were determined monthly from May through September 1981 using three tame, adult, female deer. Each sampling period consisted of observing a minimum of 1,000 bites per deer during a minimum of 2 feeding hours. Diets were determined as percent dry weight consumption by species using hand-plucked, simulated bites also collected monthly (Deschamp and others 1979). Deer grazed while roaming freely over a 740-acre (3-km^2) area during diet sampling and were kept within a 1.0-acre (0.4-ha) on-site enclosure between trials to assure their being accustomed to the vegetation. Within the enclosure, they were fed alfalfa hay ad libitum to supplement natural forages. Although some dietary variations occurred between individual deer, generally the same forages were selected, and consequently diets were pooled.

Vegetal production was determined monthly from five permanent macroplots immediately following diet determinations. The macroplot locations were selected to accurately represent the range conditions within the diet sampling area. Each macroplot was 33 x 66 ft (10 x 20 m) and permanently marked with steel posts and wood stakes. Forage production was determined by encompassing each plot with a string and obtaining weight estimates for individual species. Weight estimates were obtained by one of the following three procedures: (1) Weight of species having uneven distributions, such as perennial forbs in which individual plants could be readily counted, was estimated by multiplying the number of plants counted by the mean weight of 3 to 10 clipped plants. (2) Weight of species having relatively uniform distributions, such as grasses and some annual forbs, was estimated by obtaining clipped weights on a unit area basis (often 10 ft^2 or 1 m^2) and multiplying by the number of units within the macroplot. (3) Weight of individual shrubs was estimated using a reference branch, counting the number of equivalent branches on the shrubs, clipping the reference branch, and multiplying the clipped weight of the reference branch by the number of counted equivalent branches. These procedures were faster tha conventional double sampling techniques and were adopted because of time constraints. However, to compare accuracy, a double sampling procedure using the macroplot-microplo approach was also completed during August (Poulton and Tisdale 1961; Deschamp and others 1979). Simply, within each macroplot, weight estimates were made on 40 random located microplots with every 10th plot clipped for regression calculation. Ground cover and plant canopy cover (table 3) were also estimated. Plant samples were collected monthly for converting to dry weight production, and those species comprisi 1 percent or more of the diet during any month were analyzed for crude protein.

RESULTS

The diets of mule deer changed considerably throughout the summer (table 1). Consumption of antelope bitterbrush increased steadily reaching almost 92 percent by September. Consumption of three additional browse species declined in the late summe diet because of low abundance and prior use by both wild and tame deer. In contrast, forbs comprised most of the diet in May, but declined rapidly throughout the summer. In May and June nine and seven forb species, respectively, comprised 1 percent or more of the diet, but by July only two remained important. Abundant grasses, big sagebrush, Utah juniper, and rabbitbrushes (*Chrysothamnus* spp. Nutt.) never exceeded 1 percent of the diet.

Table 1.--Mule deer diets (percent by weight) through the summer

	Month					
Species	May	June	July	Aug.	Sept.	Mean
BROWSE						
Purshia tridentata	8.2	23.1	59.9	79.8	91.7	52.5
Symphoricarpos oreophilus	2.9	5.8	6.5	4.9	1.2	4.3
Amelanchier alnifolia	4.4	6.5	2.5	1.8	.7	3.2
Eriogonum microthecum	T*	T	2.6	.7	.0	.7
4 others	.1	.1	1.0	.2	.8	.4
Total browse	15.6	35.5	72.5	87.4	94.4	61.1
FORBS						
Commandra umbellata	3.2	10.7	15.9	5.8	1.1	7.3
Vicia americana	24.4	10.9	.0	.0	.0	7.1
Crepis accuminata	10.3	19.1	.9	.6	.1	6.2
Lithospermum ruderale	7.7	5.5	9.1	4.7	3.7	6.1
Astragalus spp.	22.2	4.2	.0	.0	.0	5.3
Agoseris glauca	4.4	.7	.0	.0	.0	1.0
Descuriana spp.	1.8	3.0	.0	.3	.0	1.0
Collinsia parviflora	3.9	.0	.0	.1	.0	.8
Delphinium nelsonii	3.4	.0	.0	.0	.0	.7
Allium accuminatum	T	3.0	.0	T	.0	.6
26 others	2.9	7.3	1.5	1.1	.7	2.7
Total forbs	84.2	64.4	27.4	12.6	5.6	38.8
GRASSES						
Total grass	.2	T	T	.0	.1	.1

*T = < 0.1 percent.

Available forage, expressed as a percent of total production, showed generally ess change over the summer (table 2). Available forage on antelope bitterbrush ncreased from May through July, but loss of leaves and flowers in August and September nd continued use by deer resulted in a sharp decline. Browse species comprised the ulk of the production, and two most abundant species, big sagebrush and Utah uniper, showed little change in production. Forbs comprised only a small proportion f the forage production and declined sharply from the early summer months. urthermore, many of the forbs were unpalatable to deer. Palatable forbs, such as merican vetch (*Vicia americana* Muhl.), grew rapidly in early spring, but cured apidly, decomposed, and were largely unavailable by July. A few species such as ayside gromwell (*Lithospermum ruderale* Dougl. ex Lehm.) had sufficiently coarse forage o remain intact through the summer. No important forb species grew in midsummer.

Table 2.--Available dry weight production percent by species through the summer

Species	May	June	July	Aug.	Sept.	Mea
BROWSE						
Purshia tridentata	6.0	18.2	26.9	14.7	12.3	15.
Symphoricarpos oreophilus	1.0	1.1	.3	.2	.1	.
Amelanchier alnifolia	T*	T	T	T	T	T
Eriogonum microthecum	T	T	T	T	T	T
Juniperus osteosperma	34.6	26.7	27.2	33.2	31.0	30.
Artemisia tridentata	29.6	34.7	29.8	30.3	36.9	32.
Chrysothamus viscidiflorus	.3	1.5	2.6	1.6	1.8	1.
3 others	T	.4	.7	1.9	2.2	1.
Total browse	71.5	82.6	87.5	81.9	84.3	81.
FORBS						
Commandra umbellata	.1	T	.1	T	T	.
Vicia americana	.6	.1	T	T	T	.
Crepis accuminata	.2	.2	.2	.2	T	.
Lithospermum ruderale	.1	.1	.1	.1	.1	.
Astragalus spp.	.6	.2	.0	.0	.0	.
Agoseris glauca	.4	T	.0	.0	.0	.
Descuriana spp.	.1	T	.0	.0	.0	
Collinsia parviflora	1.5	.0	.0	.0	.0	
Delphinium nelsonii	T	.0	.0	.0	.0	
Allium accuminatum	T	T	T	.0	.0	
Opuntia spp.	1.0	.1	.2	1.8	1.8	1
30 others	4.8	4.9	1.6	1.0	.9	2
Total forbs	9.4	5.8	2.2	3.1	2.8	4
GRASS						
Total grass	19.0	11.7	10.3	14.7	12.9	13

*T = < 0.1 percent.

Most species consumed by deer were highly preferred. The preference ration (percent dietary composition ÷ percent available production, Neff 1974) showed that al species comprising 1 percent or more of the monthly diets were preferred. Indeed, mo had ratios greater than 4.0, suggesting they were highly preferred in relation to the total plant community (Austin and Urness 1982).

The relationship ($r^2=0.96$) between the macroplot procedures for estimating production and the double sampling technique using microplots showed good agreement (table 3). Ground and plant canopy cover were about average for this vegetal type (Olson and Logan 1973).

Table 3.--Vegetative production in lbs/acre as determined by macroplot estimation and microplot double sampling, ground cover (percent), and plant cover (percent) during August 1981

Species	Technique	
	Microplot	Macroplot
BROWSE		
Purshia tridentata	149.5	116.1
Symphoricarpos oreophilus	6.2	1.8
Amelanchier alnifolia	2.0	0.2
Eriogonum microthecum	0.6	0.8
Juniperus osteosperma	238.1	262.0
Artemisia tridentata	159.9	238.7
Chrysothamnus vicidiflorus	34.6	12.9
3 others	2.0	14.9
Total browse	593.1	647.4
FORBS		
Commandra umbellata	1.6	0.2
Vicia americana	0.7	0.2
Crepis accuminata	2.0	1.7
Lithospermum ruderale	6.9	1.1
Opuntia spp.	20.0	14.4
12 others	13.5	7.8
Total forbs	44.9	25.4
GRASS		
Total grass	125.9	116.1
TOTAL PRODUCTION	763.9	788.9
GROUND COVER		
Exposed soil	24.2	--
Litter	58.8	--
Rock	14.0	--
Basal vegetation	3.0	--
PLANT CANOPY COVER	37.2	--

The percent crude protein in the forage consumed changed considerably (table 4). Crude protein levels were high in May, but declined rapidly. The few forbs that remained available through the summer were lower in crude protein than the palatable browse species. For the composite diet, percent crude protein declined from about 18 percent in May to about 8 percent by late summer when no high quality forages were selected.

Table 4.--Percent crude protein for plant species comprising 1 percent or more of the monthly diet

Species	Month May	June	July	Aug.	Sept.
BROWSE					
Purshia tridentata	13.8	10.7	8.9	7.9	8.2
Symphoricarpos oreophyllus	14.9	11.0	12.8	6.8	4.7
Amelanchier alnifolia	15.2	12.7	8.0	8.2	--
Eriogonum microthecum	--	--	10.2	--	--
FORBS					
Commandra umbellata	[1]18.0	9.4	6.3	6.5	6.4
Vicia americana	17.2	8.6	--	--	--
Crepis accuminata	19.5	8.0	--	--	--
Lithospermum ruderale	20.9	13.1	7.9	6.4	6.4
Astragalus spp.	21.8	10.6	--	--	--
Agoseris glauca	20.2	--	--	--	--
Descuriana spp.	24.0	10.5	--	--	--
Collinsia parviflora	10.0	--	--	--	--
Delphinium nelsonii	11.6	--	--	--	--
Allium Accuminatum	--	9.5	--	--	--
Weighted percent in diet	18.1	10.0	8.7	7.7	8.

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[1] Estimated.

DISCUSSION

Although Smith (1953) rated antelope bitterbrush relatively unpreferred as a summer deer forage--25th of 33 species assessed--it is important on low elevation summer ranges. Trout and Thiessen (1973) reported that antelope bitterbrush comprised 4, 1, 13, 22, and 5 percent of the monthly diets from May through September, respectively, from ranges where it made up less than 1 percent of the vegetal cover. They stated that where the shrub occurred, use by deer and cattle was heavy. Leach (1956), using rumen analyses from 29 and 16 deer, reported that antelope bitterbrush comprised 6.6 and 34.6 percent of the summer diets from two herds in California. Berg (1966) and Tueller and Monroe (1976), in comparing 13 low elevation summer deer habitats in Nevada, concluded that whenever antelope bitterbrush was found within a plant community, that community was invariably ranked among the highest in deer use. Berg (1966) further stated that the shrub was the most heavily used species in all areas where it occurred. Based on rumen analyses of sacrificed deer (five per sampli period), Doughty (1966), Deibert (1968), and Tueller (1979) reported it was an important forage in summer (table 5). The high dietary variation was caused by low sample size and changes in collection sites. Nonetheless, their data indicate the importance of antelope bitterbrush even though its maximum plant canopy cover was onl 3.8 percent.

Table 5.--Proportion of antelope bitterbrush (percent dry weight and percent frequency of occurrence in mule deer diets from Fox Mountain, Nevada

	Month					
	May		July		September	
Year	Weight	Frequency	Weight	Frequency	Weight	Frequency
1964[1]	1.7	40	50.7	100	38.8	100
1965[1]	23.7	100	55.7	100	4.7	40
1966[2]	28.7	100	21.1	100	16.4	100
1967[2]	16.4	40	17.2	100	17.6	100

[1] From Doughty 1966.

[2] From Deibert 1968.

Although our data showed that antelope bitterbrush had a considerably higher ietary contribution, especially in late summer, the study was conducted where other alatable browse species were sparse. If rumen analyses from wild deer had been used, the diet probably would have contained less bitterbrush and greater amounts of other species since mule deer generally have large home ranges which likely would have included other vegetal types (Rodgers and others 1978). Nonetheless, the important implication is that where it occurs on low elevation summer ranges antelope bitterbrush is readily consumed and preferred by deer.

Although nutritional parameters have not been strictly defined for mule deer aintenance or growth, forage quality (crude protein and digestibility) does effect arcass weights, productivity, and antler size (Julander and others 1961; Robinette and thers 1973). Einarsen (1946) estimated 5 percent crude protein was the critical level or maintenance of black-tailed deer in Oregon, and Longhurst and others (1952) stimated this level was 7 to 8 percent for mule deer in California. Maintenance evels for adult white-tailed deer ranged from about 6 to 8 percent with optimal levels f 14 to 18 percent or higher (French and others 1955; Magruder and others 1957; Murphy nd Coates 1966; Holter and others 1979). Summarizing these studies, about 7 percent rude protein appears to be an acceptable mean for body maintenance.

Consequently, for this study, the crude protein levels in the diet were excellent n May, adequate in June and July, and slightly above maintenance in August and eptember. Since bitterbrush followed the same nutritional decline but remained above percent crude protein in this study, as well as in others (Doughty 1966; Trout and hiessen 1973), we conclude that antelope bitterbrush is adequate for body maintenance f mule deer. Nonetheless, crude protein values of this shrub, as well as the combined iet, were considerably below those reported from high quality ranges where late summer alues were generally above 12 percent (Collins 1979; Pallesen 1979).

CONCLUSIONS AND RECOMMENDATIONS

1. Antelope bitterbrush is an important summer forage, palatable to mule deer. he percent dietary contribution of the shrub increased through the summer as palatable orbs and other browse species became less available.

2. Although nutritionally far from optimal, pinyon-juniper and big sagebrush mmunities used by deer in summer and containing moderate quantities of bitterbrush ould be considered as summer range. To estimate maximum potential summer er-days/ha, the following procedure is suggested:

A. Assume daily forage intake (dry weight) per deer is 3.3 lbs (1.5 kg) (Smith 1953; Bandy and others 1970).

B. Assume bitterbrush comprises 50 percent of the summer diet (table 1).

C. Assume 70 percent of bitterbrush's current annual growth is allocated fo deer, with half (35 percent) utilized in summer.

D. Divide half the allocated production, as determined in fall from ungraze plots, by the daily bitterbrush consumption.

E. Example using our figures:

$$\text{Maximum deer days per acre} = \frac{116.1 \text{ lbs/acre X } .35}{1.65 \text{ lbs/deer-day}} = 24.6 \text{ (60.9 deer-days/ha)}$$

$$\text{Deer per mi}^2 \text{ over six months} = \frac{24.6 \text{ deer-days/acre}}{180 \text{ days}} \text{ X } \frac{640 \text{ acre}}{\text{mi}^2} = 87.5 \text{ (33.8 deer/km}^2\text{)}$$

Caution must be used in applying this procedure; lower figures result from higher intake rates, increased bitterbrush in the diet, or more conservative forage allocation, and vice versa. Consumption of the shrub, as well as other deer forages, by livestock must also be considered. Furthermore, other factors including water, animal behavior, and human disturbance may be more limiting than the forage resource. Robinette and others (1977) reported a density of 61.9 deer/mi^2 (23.9 deer/km^2) on diverse low elevation summer range, but the extent of winter range was about half that of summer range.

3. Management of livestock should maximize forage availability, particularly bitterbrush, for deer while using the grass resource. Therefore, livestock should be grazed in mid- to late spring when grass is succulent, but before livestock use switches to bitterbrush and other browse (Jensen and others 1972). Berg (1966) reported that on seven areas where grazing was poorly controlled, livestock use of bitterbrush exceeded that of deer. On our study area, livestock grazing from about Ma 15 to no later than July 1 (Smith and Doell 1968) appears to be acceptable.

4. Since high quality forages are not available in late summer, the carcass condition and weight of deer would be expected, and apparently are, less than those o deer on high quality summer range (Austin 1982). This would likely result in increas mortality and decreased productivity (Julander and others 1961). Consequently, antlerless harvest of mature females should be conservative.

PUBLICATIONS CITED

Austin, D. D. The importance of various vegetal types, livestock grazing, and climate to mule deer on ranges with limited summer habitat. 1981-82 Performance Report Proj. W-105-R-A-5a-18; 1982. 10 p.

Austin, D. D.; Urness, P. J. Vegetal responses and big game values after thinning regenerating lodgepole pine. Great Basin Nat. 42(4): 512-516; 1982.

Bandy, P. J.; Cowan, I. McT.; Wood, A. J. Comparative growth in four races of black-tailed deer (Odocoileus hemionus). Part I. Growth in body weight. Can. J. Zool. 48: 1401-1410; 1970.

Berg, R. H. An evaluation of selected Nevada deer ranges: condition, forage potential and deer-livestock competition. Reno, NV: University of Nevada; 1966. 196 p. Thesis.

Collins, W. B. Feeding behavior and habitat selection of deer and elk on northern Utah summer range. Logan, UT: Utah State University; 1979. 113 p. Dissertation.

Deibert, W. J. Mule deer condition and food habits on two Nevada ranges. Reno NV: University of Nevada; 1968. 126 p. Thesis.

Deschamp, J. A.; Urness, P. J.; Austin, D. D. Summer diets of mule deer from lodgepole pine habitats. J. Wildl. Manage. 43: 154-161; 1979.

Doughty, L. A. Food habits and nutrition of mule deer (O. hemionus Refinosque) on four Nevada ranges. Reno, NV: University of Nevada; 1966. 86 p. Thesis.

Einarsen, A. S. Crude protein determination of deer food as on applied management technique. Trans. N. Am. Wildl. Conf. 11: 309-312; 1946.

French, C. E.; McEwen, L. C.; Magruder, N. D.; Ingram, R. H.; Swift, R. W. Nutritional requirements of white-tailed deer for growth and antler development. Bull. 600. University Park, PA: Pennsylvania Agricultural Experiment Station; 1955. 50 p.

Hancock, N. V.; Shields, P.; Trogstad, R. Memo from Utah Interagency Big Game Committee of the Board of Big Game Control. Salt Lake City, UT: Utah Division of Wildlife Resources; 1976. 7 p.

Holter, J. B.; Hayes, H. H.; Smith, S. H. Protein requirement of yearling white-tailed deer. J. Wildl. Manage. 43: 872-879; 1979.

Jensen, C. H.; Smith, A. D.; Scotter, G. W. Guidelines for grazing sheep on rangelands used by big game in winter. J. Range Manage. 25: 346-352; 1972.

Julander, O.; Robinette, W. L.; Jones, D. A. Relation of summer range condition to mule deer herd productivity. J. Wildl. Manage. 25: 55-60; 1961.

Kufeld, R. C.; Wallmo, O. C.; Feddema, C. Foods of the Rocky Mountain mule deer. Res. Pap. RM-111. Fort Collins, CO: U.S.Departmnet of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station; 1973. 31 p.

Leach, H. K. Food habits of the great basin deer herds of California. Calif. Fish and Game 42. 1956: 243-308.

Longhurst, W. A.; Leopold, A. S.; Dasmann, R. F. A survey of California deer herds and their ranges and management. California Fish and Game Bull. No. 6; 1952. 136 p.

Magruder, N. D.; French, C. E.; McEwen, L. C.; Swift, R. W. Nutritional requirements of white-tailed deer for growth and antler development II. University Park, PA: Pennsylvania Agricultural Experiment Station; Bull. No. 628; 1957. 21 p.

Murphy, D. A.; Coates, J. A. Effects of dietary protein on deer. Trans. North Am. Wildl. Nat. Resour. Conf. 31: 129-139; 1966.

Neff, D. J. Forage preferences of trained mule deer on the Beaver Creek watersheds. Spec. Rep. 4; Phoenix, AZ: Arizona Game and Fish Department, 1974. 61 p.

Olson, B. C.; Logan, J. R. Utah big game range inventory. Logan. Utah Wildl. Res. Publ. No. 73-1; Salt Lake City, UT: Utah Division of Wildlife Resources; 1973. 288 p.

Pallesen, J. D. Nutritive value of mule deer and elk diets and forages on lodgepole pine summer range in Utah. Logan, UT: Utah State University; 1979. 111 p. Thesis.

Poulton, C. E.; Tisdale, E. W. A quantitative method for the description and classification of range vegetation. J. Range Manage. 14: 13-21; 1961.

Robinette, W. L.; Baer, C. H.; Pillmore, R. E.; Knittle, C. E. Effects of nutritional change on captive mule deer. J. Wildl. Manage. 37: 312-326; 1973.

Robinette, W. L.; Hancock, N. V.; Jones, D. A. The Oak Creek mule deer herd in Utah Publ. No. 77-15; Salt Lake City, UT: Utah Division of Wildlife Resources; 1977. 148 p.

Rodgers, K. J.; Ffolliott, P. F.; Patton D. R. Home range and movement of five mule deer in a semidesert grass-shrub community. Res. Note RM-355; Fort Collins, CO: US Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station; 1978. 6 p.

Smith, A. D. Consumption of native forage species by captive mule deer during summer. J. Range Manage. 6: 30-37; 1953.

Smith, A. D.; Doell, D. D. Guidelines to allocating forage between cattle and big game winter ranges. Res. Publ. No. 68-11: Salt Lake City, UT: Utah Division of Wildlife; 1968. 32 p.

Trout, L. E.; Thiessen, J. L. Physical condition and range relationships of the Owyhee deer herd. Job completion Rep. Proj. W-141-R-2 Study II. Job 1. Boise, ID: Idaho Fish and Game Dept.; 1973. 37 p.

Tueller, P. T. Food habits and nutrition of mule deer on Nevada ranges. Publ. No. 128 Reno, NV: Nevada State University, Agricultural Experiment Station; 1979. 124 p.

Tueller, P. T.; Monroe, L. A. Management guidelines for selected deer habitats in Nevada. Publ. No. R104., Reno, NV: University of Nevada, Agricultural Experiment Station; 1976. 85 p.

Section 6. Soil-Plant Nutrient Relationships

OPPORTUNITIES AND APPROACHES FOR ENHANCING NITROGEN FIXATION IN PURSHIA, COWANIA, AND FALLUGIA[1]

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ABSTRACT

Although Purshia and Cowania are capable of nitrogen fixation, the ecological importance is not known. Limited observations suggest sparse nodulation may occur. There may be opportunities for enhancing nitrogen fixation utilizing an inoculum, species and ecotype selection, intergeneric hybridization, and plant breeding. Field trials are essential to demonstrate possible applications.

INTRODUCTION

Specific bacteria that infect plant roots allow the utilization of atmospheric nitrogen. The plants can then flourish and enrich the soil without expensive nitrogen fertilizer. Nitrogen fixation has long been exploited in agriculture. Rhizobium inoculants for specific legumes are commercially available and effective management of the legume symbiosis is a common agricultural practice.

Purshia (bitterbrush) and Cowania (cliffrose) are genera among certain woody angiosperms that have a symbiotic association with Frankia, an actinomycete somewhat similar to the better known legume-Rhizobium system. Both genera are important in ecological succession and are early colonizers on natural or human-induced disturbances. Symbiotic nitrogen fixation could contribute to their pioneer success. There is tremendous potential for adapting successful aspects of legume-*Rhizobium* agricultural practices to reclamation approaches using the actinorhizal association.

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Lack of knowledge of the occurrence, effectiveness, and duration of nodules on *Purshia* and *Cowania* makes it difficult to estimate their ecological importance and level of nitrogen input. In some field observations, nodulation has not been encountered (Nelson, in this proceedings). It appears that many sites are sparsely nodulated (Dalton and Zobel 1977; Nelson, in this proceedings), and in some cases nodule biomass may be insufficient for appreciable nitrogen inputs (Dalton and Zobel 1977). Drought is a likely factor where soil samples collected from sparsely nodulated sites produce abundant nodules on well-watered, greenhouse-grown seedlings (Dalton and Zobel 1977; Righetti and Munns 1981). However, soils collected from native stands sometimes produce non-nodulated seedlings even in greenhouse trials (Wagle and Vlamis 1961; Klemmedson 1979; Righetti and Munns 1981). This is especially true in surface samples where moisture and temperature stresses may be severe (Righetti and Munns 1981).

Water may be the limiting factor, making nitrogen fixation of limited ecological importance. *Fallugia paradoxa* (Apache plume) may be non-nodulating (Righetti and Munns 1981; Nelson, in this proceedings) even though a hardy pioneer. This may have implications on the ecological significance of nitrogen fixation especially if *Purshia*, *Cowania*, and *Fallugia* all evolved from a common ancestor (McArthur and others, in this proceedings). However, it seems likely that nitrogen fixation would be an advantage for these pioneer species commonly found on drastically nitrogen-deficient sites. Although nitrogen fixation rates may be much less than those associated with agricultural legumes, the nitrogen requirement for these slower-growing shrubs is substantially less. Even if nitrogen fixation input into the ecosystem is small, it may enhance survival and establishment for the species involved.

Purshia has been grown in nitrogen-free media (Bond 1976a). Although the symbiosis can provide plants with a source of nitrogen, the challenge is to bring greenhouse successes to more difficult field applications. It is conceivable that nodulation could enhance initial plant establishment, but the enhanced success has to be compared to applied nitrogen. In nitrogen-deficient soils, 4-month-old, nitrogen-supplied, greenhouse-grown *Purshia* seedlings are generally three to four times larger than nodulated ones (Righetti and Munns 1982). It may not be wise to rely on symbiotic nitrogen if an initial nitrogen application is superior. Perhaps nodulated transplants with an established symbiosis could overcome the slow symbiosis establishment that has been reported (Bond 1976a; Dalton and Zobel 1977; Righetti and Munns 1981). However, a slow-release nitrogen fertilizer in the planting medium is relatively inexpensive considering the cost of labor and the transplants themselves. Some evidence has suggested that bare root transplants are superior to container-grown transplants (Carpenter, in this proceedings). This may create difficulties for a nodulated transplant scheme as maintenance of nodulation on bare root stock may be difficult. Even if fertilized for initial establishment, the effect of the nitrogen application will disappear. Continued growth on symbiotic nitrogen would be desirable.

We know very little about capabilities or opportunities for improvement of nitrogen fixation in these shrubs. With a vigorous research effort, nitrogen fixation may be enhanced. The economic establishment of a soil-enriching, maintenance-free plant community may be obtainable. An evaluation of current research efforts and possible approaches to enhance nitrogen fixation in Purshia, Cowania, and Fallugia are presented in this paper. Studies are necessary on inoculation responses, soil fertility factors limiting nodulation, species and ecotype selection, genetic improvement, and intergeneric hybridization. Field trials will be required to evaluate any potential.

INOCULATION RESPONSES

Naturally occurring soil populations of the appropriate actinomycete seem to be adequate for actinorhizal systems inhabiting moist ecosystems, alder for example (Bond 1976b). In more xeric climates, insufficient soil populations may cause sparse nodulation. This is apparent from greenhouse trials in which soil collected from Purshia stands in eastern California was used as a growing medium with crushed nodules as an inoculum (Table 1). Nodules for the inoculum were collected at Truckee and Burcham Flat.

When inoculated with a P. tridentata crushed nodule inoculum, one of four non-nodulating soils (soil 4) and four sparsely nodulating soils (soils 3, 6, 8, 10) produced well-nodulated plants. Inoculation also increased nodule mass, total nitrogen, percent nitrogen, and shoot dry mass in some of the soils. Of the three soils failing to produce well-nodulated plants when inoculated, one produced plants that responded well to nitrogen additions but failed to nodulate under low nitrogen conditions (soil 9). A second produced severely stunted plants suggesting stresses other than nitrogen deficiency on the host (soil 2). The third (soil 7) produced plants that were not nitrogen deficient.

Subsequent studies have demonstrated that surface soil may bias the assessment of a site's nodulation capability for either Purshia or Cowania stands. Table 2 presents data from a greenhouse experiment in which Cowania seedlings were grown in surface and subsurface soil samples collected from 10 Cowania shrub communities in Arizona. Only three (soils 3, 9, and 10) of the 10 surface soils produced well-nodulated seedlings. Nodulation is usually better in subsoil samples, but even some subsoils produced few or no nodules.

Nodule masses display the same relationships as nodule number, but differences between sites and sampling depth are relatively smaller. Seedlings appear to compensate for fewer successful infections with an increase in mass per nodule.

Nitrogen inhibits nodulation, thus nitrogen-amended soils often produce fewer nodules. This is evident in the data and more apparent in shorter term experiments (Righetti and Munns 1982). Common soil nitrogen levels may inhibit nodulation, especially in surface samples. However, inoculation responses (table 1) and soil analyses indicate that nitrogen inhibition is not a major cause of sparse nodulation. It is possible that nitrogen levels not inhibitory in small container experiments with adequate water could be inhibitory in the field where drought might make nitrogen nonlimiting.

Table 1. -- Nodule number, nodule mass, shoot dry mass, and total nitrogen in the shoot for 4-month, *P. tridentata* seedlings grown in 10 different soils (from Righetti and Munns 1982).

Site identification	Nodule number	Nodule mass mg/plant (fresh)	Shoot dry mass mg/plant (dry)	Total N in shoot mg/plant
1. Burcham Flat				
uninoculated	40	90	190	4.23
inoculated	71	130	240	4.75
2. Cactus Flat				
uninoculated	0	0	173	2.02
inoculated	4	3	116	1.36
3. Chilcoot				
uninoculated	1	10	360	4.07
inoculated	56 *	203 *	396	7.48 *
4. Independence				
uninoculated	0	0	150	1.86
inoculated	29 *	143 *	230 *	4.14 *
5. Sherwin Hill				
uninoculated	34	166	380	7.11
inoculated	42	190	340	6.83
6. Shingle Mill Flat				
uninoculated	10	83	200	3.74
inoculated	82 *	180 *	316 *	7.58 *
7. Silver Lake				
uninoculated	0	0	1773	23.09
inoculated	0	0	2225	31.15
8. Truckee				
uninoculated	21	150	390	7.61
inoculated	66 *	206 *	470	9.54
9. Valyermo				
uninoculated	0	0	203	3.53
inoculated	1	10	236	3.04
10. Walker				
uninoculated	2	4	146	1.75
inoculated	41 *	130 *	280 *	5.29 *

*Indicates that values are significantly ($p = 0.05$) greater than the uninoculated treatment in the same soil.

Analysis of the data from several greenhouse trials reveals a correlation between a soil's ability to nodulate (as measured by nodule fresh mass per seedling) and the site's elevation (elev. squared, $r=0.340$, $p=0.032$) and precipitation (reciprocal precip., $r=(-)0.44$, $p=0.004$). Nodulation is often sparse or absent in samples collected from dry, low elevation locations. The most important physical or chemical soil parameter to correlate with nodulation is sodium bicarbonate-extractable phosphorus (log phosphorus, $r=0.392$, $p=0.012$). A forward multiple regression model utilizing the reciprocal of precipitation, the log of extractable phosphorus and sample depth ($r=0.344$, $p=0.05$) can account for 54 percent of the variability in nodule mass if one aberrant, high-nitrogen soil is omitted. Although

Table 2. -- Nodule number (nodules/plant) for 6-month, *C. mexicana* var. *stansburiana* seedlings grown in 10 different surface (0-20cm) and subsurface (20-40cm) soil samples with and without 56 ppm nitrogen.

	Unamended		Nitrogen-supplied	
	Surface	Subsurface	Surface	Subsurface
1. Big Springs	5	15	0	16
2. Desert View	0	1	0	0
3. Flagstaff	41	266 *	0 □	7 □
4. Fredonia	3	49 *	0	21
5. Grand Canyon	2	29	0	1
6. Jacob Lake	4	81 *	0	4 □
7. Payson	3	6	3	7
8. Prescott	6	18	3	4
9. San Francisco Peaks	29	46	8	85 *
10. Williams	46	23	35	10

* indicates that values are significantly (p = 0.05) different in the subsurface than in the surface soil.

□ indicates that values are significantly (p = 0.05) different in nitrogen amended treatment than in unamended treatment.

potassium (reciprocal potassium, r=0.480, p=0.01), magnesium (reciprocal magnesium, r=0.387, p=0.05), and sodium (reciprocal sodium, r=0.411, p=0.01) were also moderately correlated with nodulation, these variables add only 5.6% to the predictive capability of the model, and interpretation of these factors is difficult. Soil and environmental factors are important in determining the capability of a sample from a specific site to produce nodulated seedlings. Soil factors have also been correlated with the incidence of nodulation in the field.[3] Although a suitable soil population of the microsymbiont may exist at some sites, other sites, especially from harsh locations, might benefit from an inoculation. In sites where these shrubs have not been previously established, a need for inoculation is more likely.

The successful isolation of *Frankia*, the actinomycete genus infecting susceptible angiosperms (Callaham and others 1978), will allow many applications. The endophytes infecting roots at a given site may not be the most effective. The importance of incompatibility between host and microsymbionts resulting in reduced efficiency may have been underestimated. Not all *Frankia* strains are equally capable of fixing nitrogen, and ineffective strains can be isolated from natural populations. Gains could probably be made through inoculation with compatible and superior strains, thus enhancing nitrogen fixation. This approach currently is being explored and an isolation of the first *Frankia* strain for a rosaceous species, *Purshia*, appears successful.[4] The competitiveness of a superior strain with ineffective endogenous strains remains unanswered. However, if container-grown, nodulated transplants were utilized, one could be assured that at least in the short term a desirable and superior symbiosis exists. Although it appears that nodules may exist for quite some time, the longevity of nodules on these shrubs and the persistence of a superior symbiotic system cannot be predicted (Nelson, in this proceedings). If bare root transplants or seeding is the desired means of stand establishment, competition with endogenous strains may be more important. With the rapid gains occurring in endophyte culture, it may be possible to select for both competitiveness and effectiveness, circumventing problems with native ineffective strains.

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[3] Williams, S. E. Soil factors which influence nodulation of Rosaceous shrubs. Cand. J. of Microbiol. (in press).

SOIL FERTILITY FACTORS LIMITING NODULATION

Even with a suitable population and adequate moisture, optimal nodulation and nitrogen fixation could be limited by fertility constraints (Righetti and Munns 1981). In some cases, nitrogen-deficient seedlings are only sparsely nodulated even in the presence of an inoculum adequate for other soils (Righetti and Munns 1982). Salinity, soil reaction, and fertility factors may be important. Table 3 presents an example of fertilizer response.

Nodule mass, nodule number, total nitrogen in shoots, percent nitrogen in shoots and percent of root consisting of nodules generally increased with the fertilizer amendment. Nodule percentages were similar to previous studies in the same unamended subsoil (Righetti 1980) but approached solution culture values of 11 percent (Bond 1976a) when the soil was treated with phosphorus and sulfur. The increase is due to increased nodulation; root weight did not appreciably change with fertility treatments.

The response to the fertilizer amendment was more apparent for *P. glandulosa* than *P. tridentata*. *Purshia tridentata* appears to have a better symbiotic tolerance to low fertility. It may be possible to select appropriate adapted species or ecotypes capable of tolerating fertility constraints as well as modifying soils to alleviate fertility problems. The better symbiotic tolerance of *P. tridentata* to low fertility is further supported by data from Wagle and Vlamis (1961). In their 2-year study of plants grown in a nitrogen deficient soil that nodulated both species, shoot weights of *P. tridentata* were greater than *P. glandulosa* in unamended soils but similar in a soil amended with phosphorus, potassium and sulfur.

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[4] Baker, D.; McCain, R.; Seling, E. Serologic and host compatibility relationships among the isolated *Frankiae*. Cand. J. of Microbiol. (in press).

Table 3.--Nitrogen fixation parameters (per plant) for *P. tridentata* and *P. glandulosa* seedlings grown in soils with different fertility treatments (from Righetti 1980)

Nitrogen fixation parameters	Unamended soil	Phosphorus and sulfur amended soil[1]
P. tridentata:		
nodule mass (mg)	183 □	365 *
nodule number	102 □	129 □
total N (mg)	13.8 □	18.33
% N	2.56 □	2.52 □
nodule % of root	4.9	10 *
P. glandulosa		
nodule mass	65	278 *
nodule number	23	73 *
total N	6.73	14.43 *
% N	1.00	1.88 *
nodule % of root	2.3	9.0 *

[1] 50ppm phosphorus as $Ca(H_2PO_4)_2$ and 80ppm sulfur as $CaSO_4 \cdot 2H_2O$.

* indicates the parameter is significantly ($p = 0.05$) greater in the amended treatment.

□ indicates that the value reported for *P. tridentata* is significantly ($p = 0.05$) greater than the corresponding value for *P. glandulosa*.

SPECIES AND ECOTYPE SELECTION

Differences between the two *Purshia* species are not surprising considering their different ecological niches. Since ecotypes within both *Purshia* species, and *Cowania mexicana* var. *stansburiana* are known to vary tremendously across a wide range of properties, selection of superior nitrogen-fixing species or ecotypes for specific situations may prove valuable. There is some evidence that ecotypes vary in their nitrogen-fixing capability.

Differences in nodulation and growth for *P. glandulosa* seedlings grown from seeds collected from different locations have been observed (Righetti and Munns 1981). Dalton and Zobel (1977) reported that a *P. tridentata* ecotype from Utah produced ineffective nodules when grown in an Oregon soil that effectively nodulated other ecotypes. The potential and necessity for selecting appropriate species or ecotypes for a wide range of characteristics has been repeatedly emphasized throughout these proceedings, and nitrogen fixation is no exception. If the actinomycetes infecting these rosaceous plants is as variable as the hosts, a combined effort of selecting appropriate host-endophyte combinations could prove fruitful. In the short term, ecotype selection may be the best means of providing improved plant material.

GENETIC IMPROVEMENT AND INTERGENERIC HYBRIDIZATION

The remarkable variation within and hybridization between the two *Purshia* species provides a tremendous reserve for potential breeding programs. Hybridization between the two *Purshia* species and *C. mexicana* var. *stansburiana* with introgression in both directions enlarges possibilities that have been discussed in some detail (Stutz 1972; McArthur and others, in this proceedings). It is not surprising that putative hybrids between the two genera produce nodulated seedlings (Righetti and Munns 1981). Nitrogen-fixation capability could be included with whatever other characteristics are sought in breeding programs.

Fallugia paradoxa does not appear to be capable of symbiotic nitrogen fixation. Seedlings have been grown in native soils that produce nodules on related species without producing nodules on *Fallugia* (Righetti and Munns 1981; Nelson, in this proceedings), and field searches have failed to reveal nodulated plants (Nelson, in this proceedings). Expanding the host range of actinomycete-nodulated plants to include *Fallugia* could have important applications. Natural putative hybrids between *F. paradoxa* and *C. mexicana* var. *stansburiana*, a nitrogen fixing species, have been reported and attempts at artificial crosses appear successful (Blauer and others 1975). It is not known if the putative hybrid has a nitrogen fixation capability.

We have recently produced rooted cuttings of a natural putative hybrid growing at Ranger Pass, Kaibab National Forest in northern Arizona. Indole butyric acid (IBA) levels between 0 and 10,000 ppm have been tested. Rooting success increased from a negligible percentage at low levels to a maximum of 60 percent at 10,000 ppm IBA. At IBA concentrations of 3,000 ppm and above, rooting is complete within 45 days. Lower concentrations require up to 75 days to achieve their optimum rooting percentages. Although high levels of IBA produce a higher percentage of successfully rooted cuttings, less survive. None of the 10,000 ppm, IBA-treated cuttings survived. Since the putative hybrid is a unique living resource, a minimal amount of cutting material was used and a statistical evaluation was not possible. However, the following procedure is routinely used to produce cuttings of the *C. mexicana* var. *stansburiana*, *F. paradoxa*, the putative hybrid, and "F-2" hybrid seedlings.

Softwood cuttings (3 to 8 cm) are removed from field or greenhouse plants. If transportation is necessary, cuttings are stored in an ice chest during transportation to the laboratory. Upon arrival the distal ends of the cuttings are trimmed, brought in contact with a sponge saturated with a 2,000 ppm IBA, 50 percent ethanol, solution for 5 seconds, and placed in a sterile 30 percent peat, 70 percent vermiculite mix. Intermittent (15 seconds on, 7-minute interval) distilled water mist is applied for the rooting period (4 - 6 weeks). Plants are then transplanted into the desired media and returned to the mist bench. The interval between misting periods is gradually lengthened until mist is no longer required. A rooting of 33 percent with 80 percent survival is consistently achieved for field collected material. Greenhouse-grown material is more successful. Some of the rooted material has survived over a year and has been evaluated for nodulation and nitrogen fixation. Since the endophyte infecting *Cowania* roots has not been isolated, a soil mix known to produce nodulation in *Cowania* seedlings was used as a growing medium. Nodulation and acetylene reduction has been demonstrated for the putative hybrid cuttings and were similar to *Cowania* cuttings of the same size and age.

Approximately 40,000 seeds were collected from the putative hybrids in July 981. Since *Cowania* is abundant and *Fallugia* is sparse at this Arizona location, hese seeds are likely to be the product of a *Cowania* x putative hybrid backcross. f these only 150 appeared filled, and we have successfully germinated nine, two of hich died at an early stage. The remaining seven have remained vigorous and are currently being vegetatively propagated. The poor fertility was not expected and is considerably less than what we have observed in some putative *Purshia* x *Cowania* hybrids. Although both *Cowania* and *Fallugia* have been reported as having a 9n chromosome number, *Fallugia* populations recently sampled are 14n (McArthur and others, in this proceedings), and the reports on *Fallugia* (Baldwin 1951) may be in error. If this is the case, a hybrid between two genera with different chromosome numbers would be unusual and could explain the poor fertility.

Although it appears that a thorough study on hybridization between *Cowania* and *Fallugia* could provide more information on the genetics of host susceptibility to nitrogen fixation, important questions need to be addressed. We doubt whether the putative hybrids are a genuine product of *Cowania* x *Fallugia* crosses. Anatomically, with the exception of pistil number, the putative hybrid closely resembles *Cowania*. Counts of chromosomes from root tips of putative hybrid cuttings and seedlings produced from putative hybrid seed were 18. A hybrid would likely have an intermediate number between 18 (*Cowania*) and 27 (*Fallugia*). It is likely that the small population reported consists of interesting *Cowania* mutants. It is important to verify reported artificial hybridization between these two genera (Blauer and others 1975) using chromosome counts and other characterization of the progeny. Another question arises on whether *Fallugia* is truly a non-nodulating genus. Field searches and greenhouse trials involving many different populations should continue.

If *Fallugia* still appears to be a non-nodulating genus after a substantial search, nodulated "F-1" hybrid seedlings would be an indication of the feasibility of host range expansion. If viable seedlings could be produced from a hybrid x *Fallugia* cross, a breeding program could conceivably produce a nodulated *Fallugia*-like species, and have long-term implications.

A short-term selection and vegetative propagation scheme could be initiated. Seedlings from a hybrid would be genetically unique and are likely to have varying degrees of *Cowania* or *Fallugia* character, depending on the pollen source and meiotic segregation of the hybrid gamete. These unique individuals could be reproduced vegetatively and tested for many characteristics including nitrogen fixation. Similar propagation schemes using seedlings derived from *Cowania* x *Purshia* hybrids could also be useful.

FIELD TRIALS

Although the opportunities and approaches for enhancing nitrogen fixation in the rosaceous shrubs have been discussed and optimism on the potential applications of actinomycete-nodulated plants has been expressed, some caution is also necessary. There are no convincing reports that nodulation and nitrogen fixation have a substantial impact on the ecosystems inhabited by these genera or if the plants receive considerable benefit from the symbiosis in establishment, growth, or longevity. Field trials are necessary to conclusively demonstrate potential application. Any studies comparing the establishment, growth and longevity of non-nodulated and nodulated plants will add valuable information. Utilizing plants of a desirable and tested ecotype, nodulated with an efficient *Frankia* strain, is essential. Comparing establishment of nodulated versus non-nodulated (and perhaps initially nitrogen-deficient) transplants could demonstrate an ecological importance of the process, but to thoroughly assess the potential application on marginal land, it is necessary to include a nitrogen control. If a soil is drastically nitrogen deficient, it may be unwise to avoid using an initial nitrogen application unless ssured that symbiotic plants will establish equal or better stands. Field studies ugmenting water supply would be helpful in determining to what extent soil moisture s limiting nodulation and/or nodule function.

Nitrogen fixation is not a panacea and may only have an application on certain ites. It is difficult to demonstrate a nodulation response in short-run greenhouse xperiments, so one might expect similar difficulties at some field sites. Long-term enefits may be more difficult to demonstrate than an establishment trial. It may be ecessary to identify drastically nitrogen-deficient sites with low populations of ative *Frankia*. Prior to expensive, long-term field trials it may be desirable to onduct greenhouse experiments with field-collected soil. This will assure that an noculation response with the selected *Frankia* strain can occur at the field site.

Even with many questions unanswered, there is still cause for optimism. The mportance of legumes in agricultural systems adds credence to goals of utilizing hese actinorhizal nitrogen fixing systems on marginal land. Vigorous research hould proceed.

PUBLICATIONS CITED

Baldwin, J. T. Chromosomes of Spiraea and of certain other genera of Rosaceae. Rhodera 53(632): 203-206; 1951.

Blauer, A. C.; Plummer, A. P.; McArthur, E.D.; Stevens, R.; Guinta, B. C. Characteristics and hybridization of important intermountain shrubs. I. Rose Family. Res. Pap. INT-169. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1975. 35 p.

Bond, G. Observations on the root nodules of Purshia tridentata. Proc. Roy. Soc. Lond., Ser. B 192: 127-135; 1976a.

Bond, G. The results of the IBP survey of root-nodule formation in nonleguminous angiosperms. In: Nutman, P.S., ed. Symbiotic nitrogen fixation in plants. Int. Biol. Prog. No. 7. Cambridge: Cambridge University Press; 1976b: 443-446.

Callaham, D.; Tredici, P. D.; Torrey, J. G. Isolation and cultivation in vitro of the actinomycete causing root nodulation in Comptonia. Science 199: 899-902; 1978.

Dalton, D. A.; Zobel, D. B. Ecological aspects of nitrogen fixation by Purshia tridentata. Plant and Soil 48: 57; 1977.

Klemmedson, J. O. Ecological importance of actinomycete-nodulated plants in the western United States. Bot. Gaz. 140(Suppl): 591; 1979.

Righetti, T. L. Soil factors limiting nodulation and nitrogen fixation in bitterbrush (Purshia). Davis: University of California; 1980. 69 p. Dissertation.

Righetti, T. L.; Munns, D. N. Soil factors limiting nodulation and nitrogen fixation in Purshia. In: Lyons, J. M.; Valentine, R. C.; Phillips, D. A.; Rains, D. W.; Huffaker, R. C., eds. Genetic engineering of symbiotic nitrogen fixation and conservation of fixed nitrogen. New York: Plenum Publishing Corporation; 1981: 395-407.

Righetti, T. L.; Munns, D. N. Nodulation and nitrogen fixation in Purshia: inoculation response and species comparisons Plant and Soil 65: 383-396; 1982.

Stutz, H. C. Genetic improvement in crop species as contrasted with the possibilities in shrubs. In: McKell, C. M.; Blaisdell, J. P.; Goodin, J. R., eds. Wildland shrubs: Their biology and utilization. Gen. Tech. Rep. INT-1. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1972: 139-143.

Wagle, R. F.; Vlamis, J. Nutrient deficiencies in two bitterbrush soils. Ecology 42: 745; 1961.

OCCURRENCE AND NATURE OF ACTINORHIZAE ON COWANIA STANSBURIANA AND OTHER ROSACEAE[1]

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ABSTRACT

Actinorhizal root-nodulation occurred on Cowania stansburiana, Purshia tridentata, P. glandulosa, Cercocarpus ledifolius, but not on the Fallugia paradoxa plants studied in natural stands. Over 6 years, annual percentage of Cowania plants sampled varied widely. Nodule necrosis and sloughing was common. Amount of nodulation on Cowania and Purshia in greenhouse tests was much higher than found in the field. Actinorhizal nodules on cliffrose are typical of those formed on other Rosaceae.

INTRODUCTION

Wildland shrub improvement and revegetation for restoration of wildlife habitats and disturbed landscapes in the Western United States are of increasing importance and interest (Plummer and others 1968; Monsen 1975; Thames 1977; Wright 1978). Enhancing the forage productivity of western livestock ranges is becoming more essential as competition increases for more direct use of agricultural plant products for human consumption. Biological nitrogen fixation could play a vital role in maintaining the nitrogen balance in plant ecosystems (Youngberg and Wollum 1970; Evans 1975; Wollum and Davey 1975; Silvester 1977). The nature of actinomycete symbiotic nitrogen-fixation in nonleguminous plants is of broad international interest (Uemura and Sato 1975; Nutman 1976; Becking 1977; Garber and Ruddat 1979). At present, 162 species in 19 genera in 7 families of woody Dicotyledons are known to form actinomycete-type root nodules (actinorhizae) (McArthur and others 1974; Bond 1976; Heisey and others 1980; Righetti and Munns 1980). Becking (1970) proposed the family Frankiaceae (Becking) for the species of Frankia Bunchorst (Actinomycetales) to which the actinorhizal microsymbionts belong.

Among western North American shrubs of the Rosaceae are species valuable for wildlife, livestock, and revegetation use (USDA Forest Service 1937; Blauer and others 1975). Certain species of this family function as symbiotic nitrogen fixers in plant community nitrogen balance (Wagle and Vlamis 1961; Vlamis and others 1964; Lawrence and others 1967; Lepper and Fleschner 1977; Klemmedson 1979). Of the Rosaceae, 12 species in 6 genera have been found to bear actinorhizal nodules (table 1). These genera belong to the subfamily Rosoideae, and all except Rubus belong to the tribe Dryadeae as described by Engler (1964). There is some question, however, on the significance of nitrogen fixation by shrubs in the more arid regions of the Western United States (Dalton and Zobel 1977; Kummerow and others 1978).

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Table 1.--Genera and species of the Rosaceae forming symbiotic, nitrogen-fixing actinorizal nodules

Genera/species	Reference[1]	Nodulation evidence[2]
CERCOCARPUS		
C. betuloides Nutt. ex T&G	Vlamis and others 1964	GDN, NFD-(GT)
C. ledifolius Nutt.	Youngberg and Hu 1972	GDN, NFD-(GT)
	Lepper and Fleschner 1977	FDN, NFD-(AR)
C. montanus Raf.	Hoppel and Wollum 1971	FDN, NFD-(AR), MHDE
C. paucidentatus Britt.	Hoppel and Wollum 1971	FND, NFD-(AR)
CHAMAEBATIA		
C. foliolosa Benth.	Heisey and others 1980	FDN, NFD-(AR, $I^{15}N$)
COWANIA		
C. stansburiana Torr.	McArthur and others 1974	FDN
	Righetti and Munns 1980	GDN, NFD-(AR, $I^{15}N$)
DRYAS		
D. drummondii Richards	Lawrence and others 1967	FDN, NFD-($I^{15}N$, GT), MHDE
D. integrifolia Vahl	Lawrence and others 1967	FDN
D. octopetala L.	Lawrence and others 1967	FDN
PURSHIA		
P. tridentata (Pursh) DC	Wagle 1958	FDN
	Webster and others 1967	GDN, NFD-($I^{15}N$)
	Krebill and Muir 1974	MHDE
P. glandulosa Curran	Wagle 1958	FDN
	Righetti and Munns 1981	GDN, NFD-(AR)
RUBUS		
R. ellipticus Sm.	Bond 1976b	FDN
	Becking 1979	FDN-(AR)

[1] First information on the subject.

[2] FDN = Field discovered nodulation; GDN = Greenhouse demonstrated nodulation; NFD- = Nitrogen fixation demonstrated; (AR) = Acetylene reduction; ($I^{15}N$) = Isotopic (GT) = Greenhouse test, growth in nitrogen deficient soil; (MHDE) = Morphological-histological description of actinorhizae.

Although nitrogen fixation has been demonstrated for most rosaceous shrub specie known to nodulate, there is little information on nodulation frequency in the field. In *Cercocarpus*, existence of actinorhizae on *C. betuloides* is based only on nodulation of plants reared from seeds in greenhouse pots in soil from a ponderosa pine site (Vlamis and others 1964). *C. ledifolius* formed actinorhizae in greenhouse tests by Youngberg and Hu (1972) in soil known to nodulate species of *Ceanothus*, *Alnus*, and *Purshia*, but they found no actinorhizae on *C. ledifolius* in stands in central and eastern Oregon. The only record of field occurrence is on a single plant excavated in the San Bernardino Mountains of southern California (Lepper and Fleschner 1977). Hoeppel and Wollum (1971) found actinorhizae on *C. montanus* and *C. paucidentatus* on respective sites in the Sacramento and Pinos Altos Mountains of New Mexico but did not investigate nodulation frequency, although they mention that nodulation on *C. montanus* was more apparent than on the other species. In their study of *Chamaebatia foliolosa* actinorhizae, Heisey and others (1980) found no nodulation on plants in sites with 7.9 inches (20 cm) or more O. soil horizon; their discovery of nodulation was in an area with little O. horizon, but no information is given on frequency of plants nodulated. The first report of actinorhizae on *Cowania stansburiana* by McArthur and others (1974) was based on our 1973 discovery in Salt Creek Canyon east of Nephi, Utah, but no details were given. Righetti and Munns (1980) have demonstrated both nodulation and nitrogen-fixation by Stansbury cliffrose in greenhouse tests using crushed nodules collected from seedlings of *Purshia tridentata* and *P. glandulosa* reared in the greenhouse in soil known to naturally nodulate *Purshia*. They did not find naturally occurring actinorhizae on Stansbury cliffrose. The frequency of nodulated plants was not indicated by Lawrence and others (1967) on three species of *Dryas* studied in areas of recent glacier recession in Alaska, but accumulation of soil nitrogen under *Dryas* discs increased from 29 to 357 lb/acre (33 to 400 kg/ha) during the period of *Dryas* dominance. Wagle (1958) discovered actinorhizae on *P. tridentata* and *P. glandulosa* in the field but did not study frequency of nodulation, nor did Righetti and Munns (1982) in their study.

Of the rosaceous shrubs, *P. tridentata* appears to be the most frequently nodulated, but little information exists on natural incidence. Examination of *P. tridentata* root systems in two sites in the pumice region of central Oregon by Dalton and Zobel (1977) revealed that 46 percent of 364 plants excavated bore nodules. This amount is lower than encountered with other actinomycete nodulated plants such as *Alnus* that are close to 100 percent nodulated (Bond 1974). Kummerow and others (1978) found only about one-tenth the nodule density per 1.3 $\text{yd}^3(\text{m}^3)$ on southern California *Ceanothus greggii* A. Gray as reported on northern California *Ceanothus* spp. Both Kummerow and others (1978) and Dalton and Zobel (1977) concluded that the low nodulation frequency was probably related to the low moisture conditions in these semi-arid regions. Dalton and Zobel (1977) also showed that low temperatures could be a factor. They reasoned further that low amounts of nodulation probably did not result from low soil endophyte populations, because nodulation of plants grown in the same soil in greenhouses was complete. Nevertheless, nodulation in greenhouse tests does not occur in all soils taken from sites where known nodulating hosts such as *Purshia* spp. are growing (Wagle and Vlamis 1961; Righetti and Munns 1980). Addition of crushed nodule inoculum to known nodulating soil enhanced nodulation in greenhouse tests (Righetti and Munns 1981) suggests that endophyte population was well as other soil factors could be limiting nodulation. Soil N, P, and S levels apparently play a role in limiting or improving nodulation (Righetti and Munns 1981). Improved nutritional condition of the host resulting from a mycorrhizal presence, involving N, P, and Ca also apparently enhances nodulation by actinomycetes (Rose and Youngberg 1981).

The objective of this study was to provide information on occurrence and nature of actinorhizae on *C. stansburiana* and other rosaceous shrubs in the field.

METHODS AND MATERIALS

We observed the nature and morphology of root nodules on *Cowania stansburiana* (Stansbury cliffrose) during the numerous root excavations made from 1973 through 1981.

The root systems of the following shrub species were examined for actinorhizae: *Cowania stansburiana* (Stansbury cliffrose), *Purshia tridentata* (antelope bitterbrush), *P. glandulosa* (desert bitterbrush), *Cercocarpus ledifolius* (curlleaf mountain mahogany), and *Fallugia paradoxa* (D. Don) Endl. (Apache plume).

We studied the frequency of field nodulation of Stansbury cliffrose primarily on two sites, one in Salt Creek Canyon east of Nephi, Utah (elev. 5,900 ft or 1 800 m) and the other in lower Kyle Canyon (elev. 7,500 ft or 2 270 m) in the Spring Mountains of southern Nevada. Both areas were typical cliffrose sites with plants of wide age and size range. At the Salt Creek Canyon site, sparsely scattered Stansbury cliffrose, Cercocarpus betuloides and Juniperus osteosperma (Torr.) Little were the dominant shrubs on Jurassic, Arapien shale ridges. The area was highly eroded, and the soil was apparently of low fertility and extremely hard and difficult to dig. At the Kyle Canyon site, Stansbury cliffrose, Apache plume, Chrysothamnus spp., Ephedra spp., Atriplex spp., and Juniperus spp. were the dominant shrubs. The lower canyon cuts through a large bajada of predominantly limestone gravel.

We studied nodulation frequency on antelope bitterbrush on Round Mountain (elev. 7,600 ft or 2 320 m) and near Deadman Summit (elev. 8,000 ft or 2 440 m), Inyo County, California. At Round Mountain, Pinus jeffreyi Grev. & Balf. with an understory of Artemisia tridentata Nutt. and antelope bitterbrush formed the dominant vegetation. The soil was a soft volcanic ash strewn with basaltic rocks. At the Deadman Summit site, an almost pure understory of antelope bitterbrush occurred under a forest of P. jeffreyi. The soil was a coarse pumice. The two antelope bitterbrush sites were chosen partly because the soft soil allowed more complete exposure with less damage of the root systems.

At the Kyle Canyon, Round Mountain, and Deadman Summit sites, root excavations were made from 1974 through 1981. At yearly visits, all plants between 2 and 24 inches (5 and 61 cm) along 328 ft (100 m) transects were excavated with pick and shovel to a depth of 12 to 40 inches (30 to 100 cm). Roots extending beyond this depth were not examined. We recorded the range and average height of plants along with number of plants nodulated and number of nodules per plant. A single nodule or nodule cluster was judged as the product of a single infection. Both necrotic and actively growing nodules were included in the total. On the Stansbury cliffrose site at Kyle Canyon, we noted the number of actively growing and necrotic or sloughing nodules for each plant. At Kyle Canyon, excavations were made from 1974 through 1981 between July 9 and 16 (except October 9, 1974), excluding 1976. At other sites, plants were selected at random, except limited generally to plants 24 inches (61 cm) or less in height. The objective with species on these sites was to determine presence of nodulation only.

Rodents commonly make bitterbrush seed caches that result in multiple plant clumps. In 1979 at the Deadman Summit site, a disturbed area along a road recently invaded by antelope bitterbrush was selected for examination of nodulation frequency in multiple plant clumps. The objective was to examine the influence competition between plants in these clumps might have on nodulation frequency. We excavated all plants along a 984 ft (300 m) transect and noted clump height, number of plants, number of nodulated plants, number of nodules per plant, and condition of nodules.

A greenhouse test was made to research the possibility of actinorhizal formation in Apache plume and compare rates of nodulation among Stansbury cliffrose and the two species of bitterbrush. Soil was collected from the root zone of nodulated cliffrose plants at the Kyle Canyon site. After collection, we stored the soil in a coldroom at 34° ± 1°F (1° ± 0.5°C). Equal parts of the soil and a sterilized (autoclaved 2 hr at 250°F [121°C]) silica sand-vermiculite (Terra Lite) mixture were used as the test medium in Tinus-size (21.5 cu inches or 350 cc) containers (Spencer-Lemaire Inc., Edmonton, Canada). Seeds were leached for 72 hours in cold running tapwater to remove germination inhibitors, treated in 10 percent Clorox (5.25 percent Sodium Hypochlorite) to kill any surface seed-borne organisms, and then planted in washed, sterilized silica sand, in trays. In May, immediately after emergence, seedlings were transplanted in the test soil and placed in the greenhouse. Plants received natural day lengths and lighting in a fiberglass-covered greenhouse. Temperatures were held at 75° and 61°F (24° and 16°C) in summer and 50° and 34°F (10° and 1°C) in winter day-night regimes.

We applied fertilizer (Plant Marvel, Plant Marvel Laboratories, Chicago, Illinois containing a 12-31-14 NPK ratio and trace elements S, B, Cu, Mn, and Zn) to all plants immediately after transplanting at a rate of .13 oz/gal (1 g/l) to soil saturation. Thereafter, no fertilizer was added. Plants were watered when dry to soil saturation. We used 25 plants per treatment. Greenhouse contamination from possible air-borne actinorhizal fungi was checked by growing the same number of plants of each species in soil that had been autoclaved. At 9 months after planting, the soil was washed from roots and number of nodules counted. Nodulation values were arrayed according to Newman-Keul's multiple range test (Steel and Torrie 1960).

RESULTS

The actinorhizal nodules found on Cowania stansburiana ranged from single unbranched lobes usually .25 to .38 inch (1 to 1.5 mm) in diameter by .25 to .76 inch (1 to 3 mm) long (extending laterally on secondary rootlets) to massive multibranched clusters up to 2 or 2.5 inches (5 or 6 cm) diameter. The majority of nodule clusters were 0.4 to 0.8 inches (1 to 2 cm) or less in diameter. The larger nodule clusters were usually attached to the larger laterals or main tap root within 3 to 6 inches (10 to 20 cm) of the soil surface. The average nodule clusters were nearly spherical, although when formed against a hard surface they were flat and fan-shaped. Tips of actively growing nodules were almost white, turning to a light tan proceeding proximally. Patches of rust-brown corky tissue formed an irregular mosaic pattern on the surface of the most enlarged portion of nodule lobes or branches. Continuing proximally three to four branching levels, branches became shrunken to about half their maximum diameter, with a dark-brown surface of sloughing cortical material. On young, actively growing nodules, initial branching was di-, tri-, and sometimes multichotomous. With larger or older nodule clusters, branching was more symetrically dichotomous. Adjoining nodule lobes tended to branch dichotomously at a 90° angle to the opposing lobe, resulting in typical coralloid structures. Nodule clusters were found closely appressed on larger roots but were more commonly laterally or apparently terminally attached to smaller secondary roots. A closer examination revealed that nodules originated laterally as from the host pericycle. Frequently, as nodule clusters increased in size, an expression of apical-type dominance became evident (fig. 1). The root distal to a nodule point of attachment discontinued growth, shriveled, and died. Thereafter, the nodule appeared to be of terminal root origin. Increment growth of roots with attached nodules was often considerably greater than non-nodulated roots arising in the same vicinity. Expression of this apparent dominance was evident over all lateral roots arising proximally until the point where the nodulated root branched from a main root.

Table 2 summarizes data on the occurrence and frequency of nodulation on the various shrubs studied. Actinorhizal nodules were found on all species studied except Fallugia paradoxa. Of plants sampled, height ranged from 2 to 40 inches (5 to 102 cm) with an average of 12 inches (31 cm). The major portion of root systems of plants in this size range could be exposed when excavated to a depth of 12 to 40 inches (30 to 100 cm). Excavation of larger plants was too time-consuming to effectively include in the study. The data thus represents information on the smaller, likely younger, plants at the various sites. Within the 12 to 40 inch (30 to 100 cm) depths excavated, nearly all nodules were found in the upper 12 inches (30 cm) of the soil at all sites studied. From a total of all plants examined during the study, the percentage nodulated ranged as follows: 25.4 percent on Cowania stansburiana, 25.0 percent on Purshia tridentata, 12.5 percent on P. glandulosa, and 3.8 percent on Cercocarpus ledifolius.

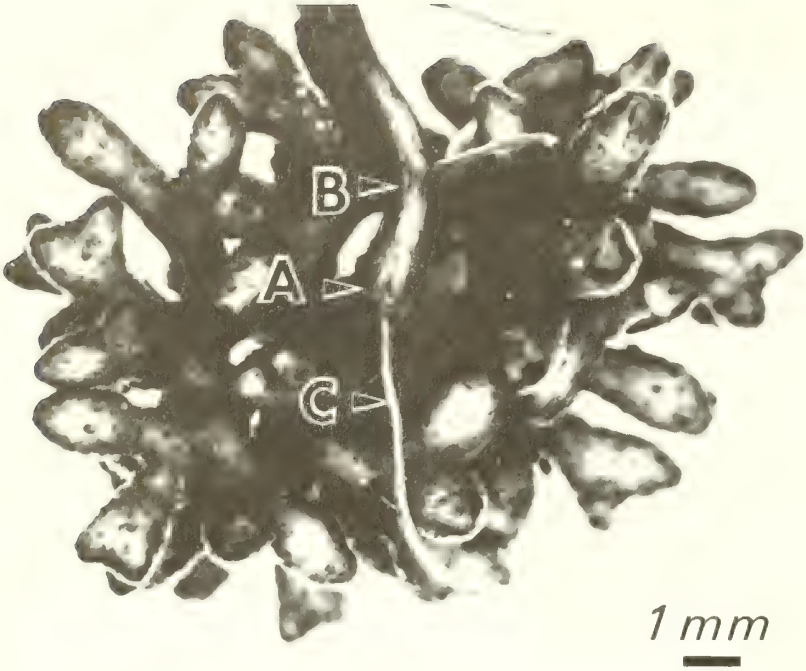

Figure 1.--1-year-old nodule cluster from Cowania stansburiana. Note nodule point of attachment (A), size of root proximal (B), and distal (C).

Table 2.--Frequency of actinorhizal nodules on shrubs in the field[1]

Shrub species	Date[3]	Location	Plant size[3]	Plants examined	Nodulated
			cm	No.	Percent
Cowania stansburiana					
	1973-74	Salt Creek Canyon Juab Co., Utah	15-31-102	48	8.3
	1979	Provo Canyon Utah Co., Utah	15-33-66	44	.0
	1974-81	Kyle Canyon Clark Co., Nevada	10-36-76	339[4]	32.2
Purshia tridentata	1974-77	Round Mountain Inyo Co., Calif.	5-25-91	294[5]	17.3
	1975-79	Deadman Summit Inyo Co., Calif.	5-25-61	884[6]	27.5
Purshia glandulosa	1973-79	Lida Summit Esmerelda Co., Nev.	15-36-61	50	12.5
Cercocarpus ledifolius	1973-79	Adams Head Mountain Garfield Co., Utah	8-31-46	57	8.8
Fallugia paradoxa	1973	Kyle Canyon Clark Co., Nev.	25-76	12	.0
	1975	Coal Creek Canyon Iron Co., Utah	25-36	15	.0

[1] Plant root systems excavated by pick and shovel.

[2] Period of years excavations were made (not necessarily on all years included).

[3] Plant average height (center) and extremes.

[4] Total plants excavated on eight 328 ft (100 m) transects.

[5] Total plants excavated on five 328 ft (100 m) transects.

[6] Total plants excavated on seven 328 ft (100 m) transects.

On the more intensively studied Cowania transects at Kyle Canyon, percentage of plants nodulated varied from 53.1 percent in 1975 to 9.4 percent in 1979 (table 3). The average number of nodules per plant ranged from 2.6 to 7.7 for the 6 years. The highest number of nodules found on a single plant was 27, with the majority having from 1 to 3. An occasional plant would have many more nodules than usual so that in most years nearly half of the nodules found were on 1 or 2 plants. Many nodules were necrotic and appeared to be completely dead (fig. 2). Others had portions that were actively growing (fig. 3). The percentage of nodules with at least some actively growing portions varied from 67.8 to 6.4 over the 6 years. There was no apparent reason for the failure to find nodules on Stansbury cliffrose at the Provo Canyon site.

Table 3.--Occurrence of actinorhizal nodules on Cowania stansburiana in Kyle Canyon[1]

Year sampled	Plant size[2]	Nodulated plants	Total nodules	Nodule range[3]	Plants nodulated	Active nodules
	cm	- - - - Number	- - - -		- - - - Percent	- - - -
1975	15-30-61	17	56	1-27 (65)	53.1	67.8
1977	8-33-51	13	49	1-20 (77)	40.6	47.5
1978	15-36-61	10	47	1-25 (70)	31.1	6.4
1979	10-28-61	3	23	2-12 (33)	9.4	17.4
1980	5-23-51	10	26	1-6 (90)	31.3	38.5
1981	8-36-61	5	32	1-19 (60)	16.0	18.6

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[1] Data from the first 32 plants 5 to 61 cm in height excavated on one transect each year.

[2] Left and right figure represents range extremes, center figure represents average height.

[3] First two figures represent range in nodule number per plant, figure in brackets is the percentage of nodulated plants with 1 to 3 nodules per plant.

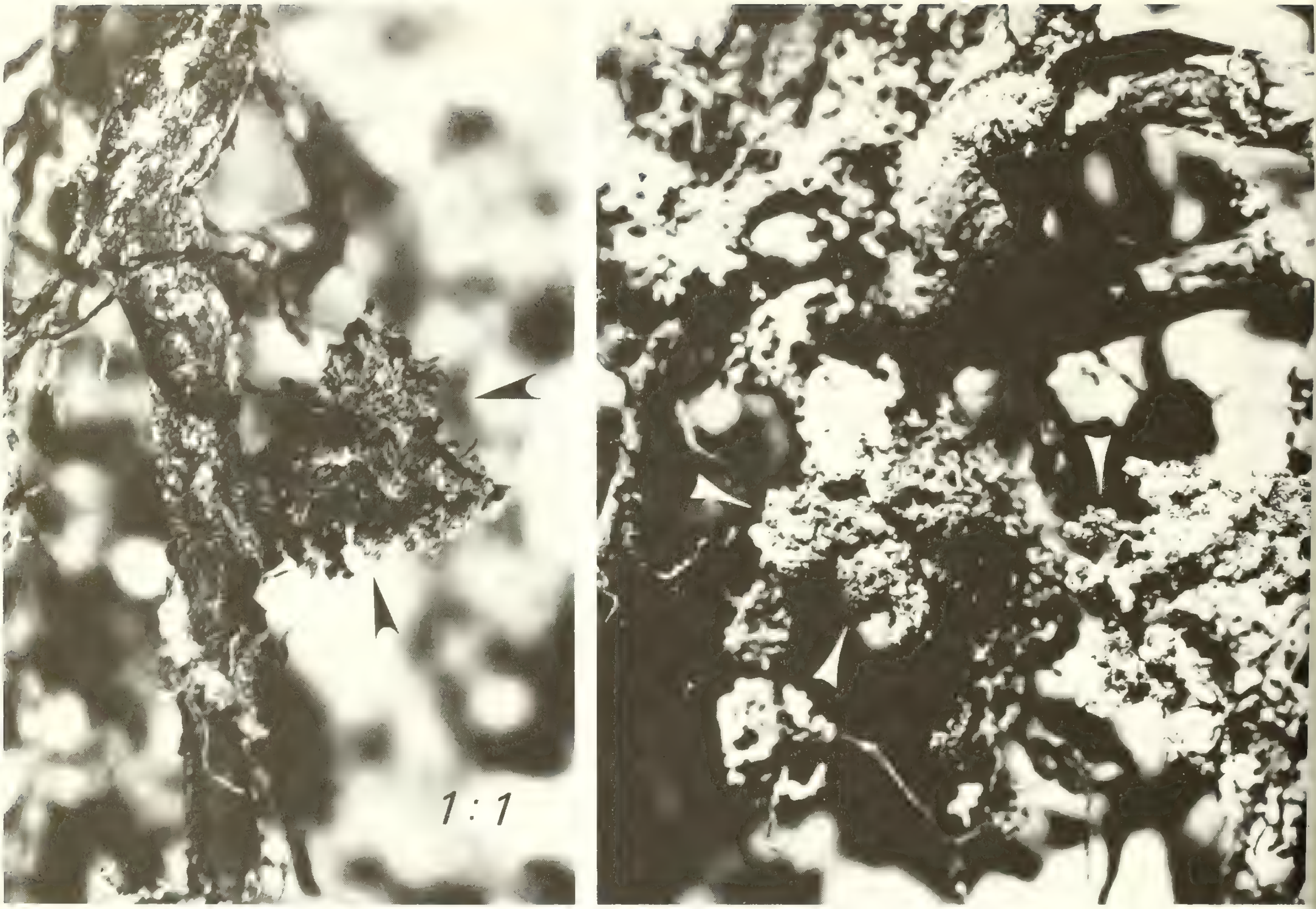

Figure 2.--Roots of a Cowania plant with numerous necrotic nodule clusters (arrows).

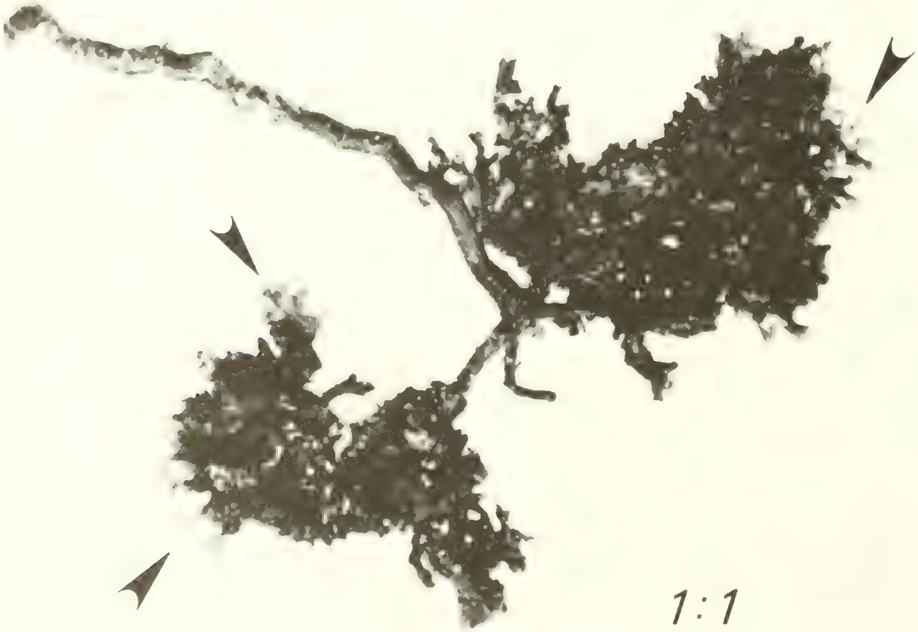

Figure 3.--Two partially necrotic nodule clusters. Note light colored active nodul lobes (arrows).

Data on nodulation of *Purshia tridentata* plants growing in multiple plant clumps as a result of rodent seed caches are given in table 4. We found up to 18 plants per clump, but those with more than 6 were not included because of the small numbers. With an increase in number of plants per clump from 1 to 6, the percentage of plants nodulated declined from 50.0 to 16.7, and the number of nodules on nodulated plants declined from 2.9 to 1.9. Only a low probability existed that any lack of correlation between increasing number of plants per clump and a decline in number of plants nodulated was not due to random chance, although the relationship is probably not linear. The percentage of actively growing nodules ranged from 83.3 to 18.2 with an increase in number of plants per clump, but there was no clear correlation.

In the greenhouse culture test, plants of all species formed actinorhizae except Apache plume (table 5). No control plants formed actinorhizae. The mean number of nodules per plant on *Cowania* was higher and clearly different from both *Purshia* species, but there was no clear difference between *Purshia* species. The variation in number of nodules per plant was high; for example, from 2 to 90 for *Cowania*. Nodule clusters appeared to be larger on plants with fewer numbers of nodules although no nodule mass data were taken. Nodules were distributed uniformly throughout root systems (fig. 4).

Table 4.--Correlation of *Purshia tridentata* actinorhizal nodulation with number of plants per clump

Plants/ clump	Clumps	Clump height	Plants nodulated	Nodules/ nodulated plant	Active nodules	Active nodules/ nodulated plant
- - Number - -		cm	Percent	Number	Percent	Number
1	42	5-28-36	50.0	2.9	83.3	2.3
2	27	5-17-33	37.0	2.6	48.1	1.3
3	23	5-20-36	24.6	2.1	42.9	.9
4	26	5-19-33	28.8	1.5	60.0	.9
5	9	3-22-38	15.6	1.6	18.2	.3
6	11	5-21-30	16.7	1.9	28.6	.5
r			-.93	-.83	-.80	-.88
p			.01	.05	.05	.05

Table 5.--Comparison of Purshia, Cowania, and Fallugia nodulation rate in greenhouse culture test

Species	Seed Source	Percent nodulated[1]	Nodules/ plant, $\bar{x}$[3]	CV[3]
Purshia tridentata	Okanogan, Washington	100	15.5a	48.4
Purshia glandulosa	Elbert Pass, California	100	11.8a	74.6
Cowania stansburiana	Kyle Canyon, Nevada	100	28.8b	72.6
Fallugia paradoxa	Richfield, Utah	0	0	0

[1] Percent of 25 plants with nodules.

[2] Values followed by the same letter are not significantly different according to Newman-Keul's multiple range test at P = 0.05.

[3] Coefficient of variation.

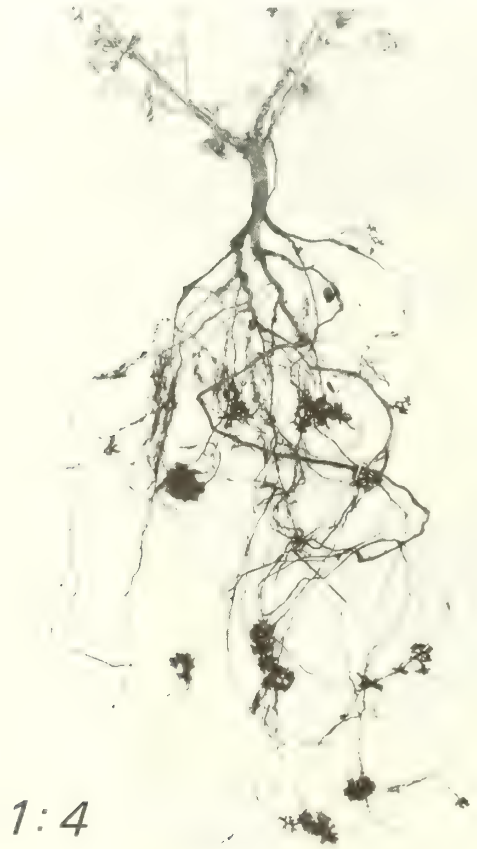

Figure 4.--2-year-old Cowania plant from greenhouse test. Note distribution of nodule clusters throughout the root system.

DISCUSSION AND CONCLUSIONS

Root nodules on *Cowania stansburiana*, like other actinomycete-induced nodules, were modified roots. Nodules on *Cowania*, like *Purshia*, *Cercocarpus*, and *Dryas*, developed into distinctly indeterminate coralloid clusters. Nodule lobes on *Cowania* branch di- to multi-chotomously by apparent division of the nodule tip meristem. No distinctly lateral or pericyclic branching, as in *Ceanothus* nodules (Strand and Laetsch 1977), was observed, and no nodule roots were observed as in *Myrica* nodules (Torrey and Callaham 1978). A closer comparison with the *Alnus*-type nodules may show that actinorhizal nodules of the Rosaceae are morphologically distinct. A definite apical-like dominance is expressed by actinorhizae of *Cowania*. Nodulated roots are distinctly larger than non-nodulated lateral roots of comparable age. This dominance is possibly a hormone-related phenomenon and likely ensures longevity of nodules, larger volume of vascular translocation, and more secure attachment of nodules. Presence of higher levels of growth hormone activity in actinomycete-induced nodules than in roots has been demonstrated in *Alnus glutinosa* (L.) Gaertn. nodules: indol-3yl-acetic acid (IAA) and others (Dullaart 1970), cytokinis (Bermudez DeCastro and others 1979), and IAA, cytokinins and gibberellin-like substances (Wheeler and others 1979). Interest has focused on their role in nodule development and microsymbiont function. The possibility of a hormonal role in a nodulated-root dominance needs to be considered.

Purshia glandulosa likely represents a stabilized hybrid between *P. tridentata* and *Cowania stansburiana*, and the three taxa form hybrid swarms where their ranges overlap (Stutz and Thomas 1964). Gene introgression occurs commonly, sometimes far beyond points of range overlap (Stutz and Thomas 1964; Nord 1965). Because of this close relationship, it is not unexpected that *Cowania*, as noted by Righetti and Munns (1980), would be found to form an actinorhizal symbiosis similar to *Purshia*. *Fallugia paradoxa* is classed in the tribe Dryadeae as are all nodulating Rosaceae, except *Rubus*, and is probably quite closely related to *Cowania* as indicated by experimental and possible natural hybrids (Blauer and others 1975). *Fallugia* did not nodulate in *Cowania*-nodulating soil in the greenhouse test in this study nor in those of Righetti and Munns (1981). Our limited sampling in the field was negative, and those excavated at Kyle Canyon were in a mixed stand with *Cowania* on which nodules were found. More extensive field sampling would provide a more reliable conclusion on existence of nodulation in this genus.

The frequency of nodulation in native rosaceous shrub species in this study was low, compared to other groups of actinorhizal plants that have been reported to be close to 100 percent nodulated. Frequency rates appeared generally lower than that found by Dalton and Zobel (1977) on *P. tridentata* in Oregon, and more comparable to that found on southern California chaparral *Ceanothus* spp. (Kummerow and others 1978). Information on frequency of nodulation in the field was limited by the method used in excavating root systems. Also, deeper roots were difficult to reach, and sampling was primarily limited to smaller plants. Although nodulation frequency on arid and semi-arid land species of Rosaceae appears low, there remains a potential for ecological significance because nitrogen is generally deficient in semiarid regions.

The frequency of nodulation of *Cowania* at the Kyle Canyon site appeared to vary considerably from year to year during the 6 years sampled. Possible explanations could be that (1) the sample size was too small to account for variation caused by low frequency, or (2) nodulation rate varied with fluctuating amounts of effective annual precipitation. Until this variation can be accounted for, it would seem that a true evaluation of frequency cannot be based on a single year's data. Wagle and Vlamis 1961) obtained no nodulation of *Purshia* plants grown in soil from the same Deadman ummit site where an average of 27.5 percent of Purshia plants nodulated were found table 2) in this study. This disparity suggests that greenhouse bioassay of odulation potential of field soil also needs further study.

The low percentage of actively growing nodules was unexpected, but there was no reason to think it was unusual. The yearly variation in amount of sloughing was roughly correlated with the percentage of plants nodulated. Nodules may slough during unusually dry years, or it could be a seasonal occurrence and the time of year that sloughing occurs varies with seasonal distribution of precipitation. Kummerow and others (1978) found few living and large amounts of decaying nodules on *Ceanothus greggii* in summer and fall when host water potentials were low. A single watered plan retained actively growing nodules into late summer. Time of year when sampling is don could, therefore, be an important factor in estimating frequency of field nodulation. The seasonal decomposition rate of sloughing or senescent nodules is unknown. Only portions of some nodules slough. One might speculate that evolution has been toward a system where nodules tend to slough during periods of low moisture, providing a flush of available nitrogen for rapid growth during short periods of high moisture. The reason for an occasional nodulated plant having many more nodules than usual was not evident. No apparent differences in soil moisture or other soil factors existed. Perhaps these plants were genetically more compatible symbionts, and differences are masked except when limiting soil factors are critical.

In the multiple-plant clumps of *Purshia tridentata*, the number of plants nodulate and possibly the number of actively growing nodules declined with an increase in numbe of plants per clump. It might be assumed that all plants within the clump are equall exposed to the soil-borne, nodule-endophyte propagules. A possible explanation for th decline would be a competition for water and soil nutrients such as N, P, and S that influence nodulation (Righetti and Munns 1980) and the nutrient deficient status of plants resulting from the competition. Proper balance of P and Ca in *Ceanothus velutinus* resulting from presence of vesicular-arbuscular mycorrhizae increased the frequency and function of actinomycete nodulation, according to information by Rose an Youngberg (1981). Nitrogen deficiency resulting from competition between plants in th clump should, however, tend to enhance nodulation.

The amount of nodulation of *Cowania* and *Purshia* plants in the greenhouse culture test was much higher than found on plants examined in the field. Moisture, temperature, and plant nutrient balance were possibly more favorable and could accoun for this difference although the study was not designed to test these factors. Initi addition of nitrate certainly did not greatly inhibit nodulation. Righetti and Munns (1981) tested soil factors and found that addition of P and S enhanced nodulation. Dalton and Zobel (1977) obtained similar increased rates of nodulation of *Purshia* in greenhouse tests. The number of nodules forming on *Cowania* was significantly higher than on the two *Purshia* species. And because the *Cowania* seed and test soil were fro the same site and the *Purshia* seed source was different, there could be suggestion of endophyte-host specificity. The number-of-nodule basis for comparing nodulation amon these species was a measure of infectivity rather than nitrogen-fixation. Size of nodule clusters appeared inversely correlated with higher numbers of nodules per plan although no data were taken to establish this.

The difficulty encountered in culturing the *Frankia* endophyte in absence of its host, and failure thus far to find a natural saprophytic phase, suggest an obligate parasitism. In general, obligate parasites infect and grow better in a healthy, vigorously growing host. If nitrogen deficiency in the host enhances infection, it i inconsistent but perhaps unique with a *Frankia* obligate parasitism.

PUBLICATIONS CITED

Becking, J. H. Frankiaceae fam. nov. (Actinomycetales) with one new combination and six new species of the genus *Frankia* Bunchorst 1866. Intern. J. Syst. Bacteriol. 20: 201-220; 1970.

Becking, J. H. Dinitrogen-fixing associations in higher plants other than legumes. In: Hardy, R. W. F.; Silver, S. W. eds. A treatise on dinitrogen fixation, sec. III: biology. New York: John Wiley, 1977: 185-275.

Becking, J. H. Nitrogen fixation by *Rubus ellipticus* J. E. Smith. Plant and Soil 53: 541-554; 1979.

Bermudez DeCastro, F.; Canizo, A.; Costa, A.; Miguel, C.; Rodriguez-Barrueco, C. Cytokinins and nodulation of the non-legumes (*Alnus glutinosa* and *Myrica gale*). In: Newton, W.; Postgate, J. R.; Rodriguez-Barrueco, C. eds. Recent developments in nitrogen fixation: 2d International symposium on nitrogen fixation: Salamanca, Spain. London: Academic Press; 1977: 539-549.

Blauer, A. C.; Plummer, A. P.; McArthur, E. D.; Stevens, R.; Giunta, B. C. Characteristics and hybridization of important Intermountain shrubs. I. Rose family. Res. Pap. INT-169. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1975. 36 p.

Bond, G. Root-nodules symbioses with actinomycete-like organisms. In: Quispel, A., ed. The biology of nitrogen fixation. Amsterdam: North Holland; 1974: 342-378.

Bond, G. The results of the IBP survey of root-nodule formation in non-leguminous angiosperms. In: Nutman, P. S. ed. Symbiotic nitrogen fixation in plants. Int. Biol. Progr. No. 4. Cambridge, England: Cambridge University Press; 1976: 443-475.

Dalton, D. A.; Zobel, D. B. Ecological aspects of nitrogen fixation by *Purshia tridentata*. Plant and Soil. 48: 57-80; 1977.

ullaart, H. The auxin content of root nodules and roots of *Alnus glutinosa* (L.) Vill. J. Exp. Bot. 21: 975-984; 1970.

ngler, A. Syllabus der Pflanzenfamilien, 12th ed. (Melchior, H. ed.), Vol. 2. Berlin: Gebruer Bornlraeger; 1964. 666 p.

vans, H. J., ed. Enhancing biological nitrogen fixation. In: Energy related research and Division of Biological and Medical Sciences of the National Science Foundation: proceedings of the workshop; 1974 June 6; Washington, D.C.; 1975. 52 p.

arber, E. D.; Ruddat, M., eds. Symbiotic nitrogen fixation in actinomycete-nodulated plants. Bot. Gaz. (Suppl.) 140: S1-S126. Chicago, IL: University of Chicago Press; 1979.

eisey, R. M.; Delwiche, C. C.; Virginia, R. A.; Wrona, A. F.; Bryan, B. A. A new nitrogen-fixing nonlegume: *Chamaebatia foliolosa* (Rosaceae). Am. J. Bot. 67: 429-431; 1980.

eppel, R. E.; Wollum, A. G., II. Histological studies of ectomycorrhizae and root nodules from *Cercocarpus montanus* and *Cercocarpus paucidentatus*. Can. J. Bot. 49: 1315-1318; 1971.

Klemmedson, J. O. Ecological importance of actinomycete-nodulated plants in the wester United States. Bot. Gaz. (Suppl.) 140: S91-S96. Chicago, IL: University of Chicago Press; 1979.

Krebill, R. G.; Muir, J. M. Morphological characterization of Frankia purshiae, the endophyte in root nodules of bitterbrush. Northwest Sci. 48: 266-268; 1974.

Kummerow, J.; Alexander, J. V.; Neel, J. W.; Fishbeck, K. Symbiotic nitrogen fixation in Ceanothus roots. Am. J. Bot. 65: 63-69; 1978.

Lawrence, D. B.; Schoenike, R. E.; Quispel, A.; Bond, G. The role of Dryas drummondii in vegetation development following ice recession at Glacier Bay, Alaska, with special reference to its nitorgen fixation by root nodules. J. Ecol. 55: 793-813; 1967.

Lepper, M. G.; Fleschner, M. Nitrogen fixation by Cercocarpus ledifolius (Rosaceae) in pioneer habitats. Oecologia (Berl.). 27: 333-338; 1977.

McArthur, E. D.; Giunta, B. C.; Plummer, A. P. Shrubs for restoration of depleted ranges and disturbed areas. Utah Sci. 35: 28-33; 1974.

Monsen, S. B. Selecting plants to rehabilitate disturbed areas. In: Campbell, R. S.; Herbel, C. H., eds. Improved range plants. Denver, CO: Society for Range Management; 1975: 76-90.

Nord, E. C. Autecology of bitterbrush in California. Ecol. Monogr. 35: 307-334; 1965.

Nutman, P. S., ed. Symbiotic nitrogen fixation in plants. Int. Biol. Progr. No. 7. Cambridge, MA: Cambridge University Press; 1976. 584 p.

Plummer, A. P.; Christensen, D. R.; Monsen, S. B. Restoring big game range in Utah. Publ. 68-3. Salt Lake City, UT: Utah Division of Fish and Game; 1968. 183 p.

Righetti, T. L.; Munns, D. N. Nodulation and nitrogen fixation in cliffrose (Cowania mexicana var. stansburiana [Torr.] Jeps.) Plant Physiol. 65: 411-412; 1980.

Righetti, T. L.; Munns, D. N. Soil factors limiting nodulation and nitrogen fixation Purshia. In: Lyons, J. M.; Valentine, R. C.; Phillips, D. A.; Rains, D. W.; Huffaker, R. C. eds. Genetic engineering of symbiotic nitrogen fixation and conservation of fixed nitrogen. Plenum Publ. Corp. 1981: 395-407.

Righetti, T. L.; Munns, D. N. Nodulation and nitrogen fixation in Purshia: inoculatic responses and species comparisons. Plant and Soil 65: 383-396; 1982.

Rose, S. L.; Youngberg, C. T. Tripartite associations in snowbrush (Ceanothus velutinus): effect of vesicular-arbuscular mycorrhizae on growth, nodulation, ar nitrogen fixation. Can. J. Bot. 59: 34-39; 1981.

Silvester, W. B. Dinitrogen fixation by plant associations excluding legumes. In: Hardy, R. W. F.; Gibson, A. H., eds. Sec. IV: Agronomy and ecology. New York: Wiley and Sons; 1977: 141-190.

Steel, G. D.; Torrie, J. H. Principles and procedures of statistics. New York: McGraw-Hill; 1960. 481 p.

Strand, R.; Laetsch, W. M. Cell and endophyte structure of the nitrogen-fixing root nodules of Ceanothus integerrimus H. and A. II. Progress of the endophyte into young cells of the growing nodule. Protoplasma. 93: 179-190; 1977.

Stutz, H. C.; Thomas, L. K. Hybridization and introgression in *Cowania* and *Purshia*. Evolution. 18: 183-195; 1964.

Thames, J. L., ed. Reclamation and use of disturbed lands in the Southwest. Tucson, AZ: University of Arizona Press; 1977. 362 p.

Torrey, J. G.; Callaham, D. Determinate development of nodule roots in actinomycete-induced root nodules of *Myrica gale*. Can. J. Bot. 56: 1357-1364; 1978.

Uemura, S.; Sato, T. Non-leguminous root nodules in Japan (a supplementary report). In: Takahashi, H., ed. Nitrogen fixation and nitrogen cycle. Tokyo: J.I.B.P., Tokyo Press; 1975: 17-24.

U.S. Department of Agriculture, Forest Service. Range Plant Handbook. Washington, DC: U.S. Government Printing Office; 1937. 536 p.

Vlamis, J.; Schultz, A. M.; Biswell, H. H. Nitrogen fixation by root nodules of western mountain mahogany. J. Range Manage. 17: 73-74; 1964.

Wagle, R. F. Early growth in bitterbrush and its relation to environment. Berkeley, CA: University of California; 1958. 271 p. Thesis.

Wagle, R. F.; Vlamis, J. Nutrient deficiencies in two bitterbrush soils. Ecology. 42: 745-752; 1961.

Webster, S. R.; Youngberg, C. T.; Wollum, A. G. II. Fixation of nitrogen by bitterbrush (*Purshia tridentata* [Pursh] DC.). Nature (London). 216(5113): 392-393; 1967.

Wheeler, C. T.; Henson, I. E.; McLaughlin, M. E. Hormones in plants bearing actinomycete nodules. Bot. Gaz. (Suppl.) 140: S52-S57. Chicago, IL: University of Chicago Press; 1979.

Wollum, A. G. II; Davey, C. B. Nitrogen accumulation, transformation, transport in forest soils. In: Bernier, B.; Winget, C. H. eds. Forest soils and forest land management. Laval, Quebec: Les Presses del'Universite; 1975: 67-106.

Wright, R. A., ed. The reclamation of disturbed arid lands. Albuquerque, NM: University of New Mexico Press; 1978. 196 p.

Youngberg, C. T.; Wollum, A. G. II. Nonleguminous symbiotic nitrogen fixation. In: Youngberg, C. T.; Davey, C. B., eds. Tree growth and forest soils. Corvallis, OR: Oregon State University Press; 1970: 383-395.

oungberg, C. T.; Hu, L. Root nodules on mountain mahogany. For. Sci. 18: 211-212; 1972.

RESPONSE OF BITTERBRUSH AND ASSOCIATED PLANT SPECIES TO BROADCAST NITROGEN, PHOSPHORUS, AND SULFUR FERTILIZATION[1]

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ABSTRACT

The effect of three annual fall applications of a nitrogen (N), phosphorus (P), and sulfur (S) fertilizer on bitterbrush (Purshia tridentata [Pursh] DC) cover, leader growth, crude protein, and understory vegetation cover and biomass was studied in bitterbrush habitats in north-central Washington 1973 through 1976. Eight replications of treatments were established: unfertilized/not covered, unfertilized/covered, fertilized/not covered, and fertilized/covered. Nitrogen, P, and S were applied at annual rates of 67, 29, and 10 lbs/acre (75, 33, and 11 kg/ha) respectively. Bitterbrush cover varied widely among years from 16 to 32 percent (average of all treatments) and was a reflection of the August through February precipitation, but there were no significant differences among treatments for bitterbrush vegetative cover in any year. Current annual leader growth also varied among years in response to differences in August through February precipitation. In 1974, leader length of the fertilized/not covered treatment was significantly less than the fertilized/covered treatment indicating an attractant effect of fertilized plants for mule deer. Crude protein levels did not appear to respond to fertilization.

Biomass and cover of herbaceous understory responded significantly to fertilization and to fertilization and protection indicating that fertilization is an effective means of improving protective watershed cover. Calculated uptakes of N, P, and S by understory vegetation indicated that the major proportion of applied nutrients was available for bitterbrush growth.

The failure of bitterbrush to respond to fertilization is probably a consequence of the over-mature, decadent nature of these stands.

The relationships established between August through February precipitation and bitterbrush cover and leader growth should be a valuable predictive tool for bitterbrush production in this area.

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INTRODUCTION

Antelope bitterbrush (Purshia tridentata [Pursh] DC) is a prominent rosaceous shrub of low- to mid-elevation vegetative habitats (700 to 2,000 ft [200 to 600 m]) of the mid-Columbia region of eastern Washington (Daubenmire 1970; Franklin and Dyrness 1973). In addition to the documented importance of bitterbrush as a major component of the winter and early spring diet of mule deer (Odocoileus hemionus hemionus) (Burrell 1982), its continued productivity and vigor are essential to maintenance of watershed stability on these steep erosive slopes. Decadence and high plant mortality of bitterbrush are problems that have significance for continued wildlife productivity and land stability in many habitats where this plant is a major component of the vegetation. Driver and others[3] surveyed bitterbrush communities in four mid-Columbia areas of north-central Washington using the rating system developed by Patton and Hall (1966)[4]. Two of the areas they surveyed were near areas of the present study. At all four locations, most plants were in mature or decadent age classes.

Absence of seedlings and young plants in these areas indicates a possible shift in community composition. Without recruitment of bitterbrush, vegetative composition may shift to dominance of annual and perennial grasses, forbs, and halfshrubs.

In some areas, no vegetation succeeds dying bitterbrush. The result is substantial erosion, road maintenance problems, and deterioration of water quality. Erosion establishes a subtle epicycle of reduced productivity and surface protection, reduced stability, increased erosion, and further reduction of productivity. The end result may be a soil material so low in nutrients and water-holding capacity that plant growth cannot be supported.

Commercial fertilizers hold promise for enhancing plant growth and restoring stability to unstable, eroding wildland sites. In other studies, soil nitrogen (N) and sulfur (S) have been determined to be moderately to severely deficient in amount and availability in several East Cascade soils (Tiedemann 1972; Tiedemann and Klock 1977; Klock and others 1971, 1975). Leman and Pittack[5] conducted a field fertilization trial in eastern Washington, using 130 lb of N per acre (146 kg/ha) applied to individual shrubs as Ortho unipel ANS 30-10-0-6 (N, phosphorus (P), potassium (K), and S) and Ortho unipel ANS 16-16-16-0 (NPKS). They found an increase in available forage on bitterbrush plants classed as mature, but did not obtain a response from plants classed as decadent. Bayoumi and Smith (1976) studied the response of native stands of antelope bitterbrush to applications of N and P fertilizer alone and in combination. Nitrogen applied at 30, 60, 96, and 149 lbs/acre (34, 67, 108, and 168 kg/ha) to individual bitterbrush plants resulted in statistically significant increases in twig growth, seed production, and crude protein percentages.

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[3] Driver, Charles H., T. A. Hanley, I. Olmstead, and others. Decadence in antelope bitterbrush--a management problem and solution. Final report of a cooperative agreement with the Pacific Northwest Forest and Range Experiment Station. Copy on file at Forestry Sciences Laboratory, Wenatchee, Washington.

[4] S Seedling: Plant up to 3 years old that has become firmly established, usually less than 0.125 inch (.3 cm) diameter.

Y Young plant: Larger with more complex branching and more fibrous bark than seedling, does not show signs of maturity, usually between 0.125 and 0.2 inch (.3 cm and .5 cm) diameter.

M Mature plant: Complex branching, rounded growth form, larger size; seed produced on healthy plants; generally larger than 0.25 inch (.63 cm) diameter.

D Decadent: Plant, regardless of age, that is in a state of decline; usually evidenced by 25 percent or more dead branches.

[5] Leman, B., and C. C. Pittack. 1969. Pilot study. Pruning and fertilization of itterbrush on the Swakane Game Range. Unpublished report on file with Chelan Co. UD, Wenatchee, Washington.

Neither of these fertilization studies addressed the integrated plant community response to fertilization. The prominence of cheatgrass (Bromus tectorum L.) in the bitterbrush habitats of the mid-Columbia necessitates an assessment of the total community response because cheatgrass responds readily to N and S fertilization (Klemmedson and Smith 1964) and may reduce the effectiveness of applied nutrients for bitterbrush. A more practical reason for evaluating the total community response is that aerial broadcast application is the only feasible means for fertilizing many sites--the results must reflect the response that would occur on an operational basis. A 3-year study to assess the response of bitterbrush habitats to N, P, and S fertilization had the following objectives:

1. Assess the fertility status of surface soils in three representative mid-Columbia bitterbrush habitats.
2. Evaluate effectiveness of three annual fall broadcast applications of a nitrogen-phosphorus-sulfur fertilizer for promoting growth and increasing crude protein content of bitterbrush.
3. Measure response of associated plant species to fertilization and estimate N, P, and S uptake by these species.
4. Measure mule deer use of bitterbrush and understory species in response to fertilization.

APPROACH

In the fall of 1973, eight sites were selected in the Entiat, Swakane, and Oklahoma gulch areas north of Wenatchee, Washington. These eight sites served as replications for the fertilizer study.

Areas of the study sites generally drain to the southeast into the Columbia River between Chelan and Wenatchee, Wash. All plots are situated on southerly facing slopes. Soils in all three areas are derived primarily from granitic parent material and are generally coarse and erosive (McColley 1976). Slopes are very steep, with relief of 30 to 40 percent. Bitterbrush is the predominant shrubby species. Big sagebrush (Artemisia tridentata ssp. tridentata) and serviceberry (Amelanchier alnifolia Nutt.) are the principal associated shrubby species. Prominent halfshrubs are snow eriogonum (Eriogonum niveum Dougl.), Wyeth buckwheat (E. heracleoides Nutt.), and Phlox (Phlox sp.). Arrowleaf balsamroot (Balsamorhiza sagittata [Pursh] Nutt.) and yarrow (Achillea millefolium L.) form the major portion of perennial forb cover. Cheatgrass (Bromus tectorum L.) dominates cover of gramineous plants, but bluebunch wheatgrass (Agropyron spicatum [Pursh] Scribn. and Smith) and western needlegrass (Stipa occidentalis Thurb.) are common.

Two different techniques were used to assess fertility of soils. The first involved determination of the concentrations of total N and total S in surface soils prior to fertilization. Total P was not measured in these soils because of a moratorium in effect at the time of the study preventing use of perchloric acid digestions at the Pacific Northwest Forest and Range Experiment Station.

Prior to fertilization in fall 1973, total N (Bremner and Tabatabai 1972), total organic carbon, pH (Black and others 1965), and total S (Tiedemann and Anderson 1971) were measured in soils from the surface 2 inches (5 cm) of areas beneath bitterbrush plants and an adjacent opening at each of the eight locations (replications). Areas under shrubs were sampled to serve as reference levels of nutrient constituents, organic carbon, and pH, that would be expected for this site in equilibrium with the climate, organisms, relief, and soil parent materials. The levels of nutrient constituents, organic carbon, and pH in open areas were indicative of soil fertility and soil chemistry throughout the study area and were used to indicate the potential for success of fertilization. A "t" test was used to evaluate differences in soil characteristics between areas under shrubs and open areas.

Availabilities of individual macronutrients; N, P, K, and S, the second parameter of fertility, were determined for surface soils of the study sites by the bioassay technique of Jenny and others (1950). Briefly, this greenhouse pot trial involves successive deletion of individual nutrients from a full nutrient treatment. Response to nutrient deletion is determined by measuring the biomass yield of a test species following a defined period of growth. Nutrient availability is expressed as the relative yield (RY) of each individual nutrient. Relative yield is the ratio of biomass yield with the treatment from which a nutrient was deleted to the yield with the full nutrient treatment. For example:

$$\mathrm{RYN} = \frac{\text{yield of treatment with no added N}}{\text{yield with full nutrient treatment}} \times 100$$

Soils were collected from the surface 2 inches (5 cm) between bitterbrush plants near each of the sites for the fertilization study. These collection areas served as replications for the pot trial. Replication was carried through to the greenhouse. Soils were air dried to constant weight at about 20°C and sieved through a 4 mm mesh screen. After filling pots with 1200 g of soil, the following nutrient treatments were applied:

1.	Check	No nutrients added
2.	No nitrogen (N_0)	$N_0\ P_{100}\ K_{50}\ S_{50}$
3.	No phosphorus (P_0)	$N_{100}\ P_0\ K_{50}\ S_{50}$
4.	No potassium (K_0)	$N_{100}\ P_{100}\ K_0\ S_{50}$
5.	No sulfur (S_0)	$N_{100}\ P_{100}\ K_{50}\ S_0$
6.	Full nutrient treatment	$N_{100}\ P_{100}\ K_{50}\ S_{50}$

Subscript refers to the approximate application rates in kg/ha. Nitrogen was added as ammonium nitrate (NH_4NO_3), P as sodium mono-hydrogen phosphate (Na_2HPO_4), K as potassium chloride (KCl), and S as calcium sulfate ($CaSO_4$).

Ten seeds of bitterbrush were planted in each pot. Following establishment, plants were thinned to 3 plants/pot. Plants were grown under natural light in a greenhouse with day temperatures at about 27°C (80°F) and night temperatures at bout 13°C (55°F). Distilled water was added as the soil surface dried. At the nd of 22 weeks, plants were harvested and oven dried at 60°C to constant weight. A one-way analysis of variance was used to analyze statistical significance of ifferences among treatments for absolute yields (Steele and Torrie 1960). The uncan multiple range test was used to separate differences among means of absolute ields. Relative yields were calculated but not tested statistically because they re determined from absolute yields.

For the field fertilizer trial, four 6.3 x 32.8 ft (2 x 10 m) plots were stablished at each of the eight sites. Half the plots at each of the eight locations (replications) were fenced and covered with 3.3 inch (10 cm) mesh wire fence. Half the plots were fertilized with three consecutive, yearly, fall applications (1973, 1974, and 1975) of ammonium nitrate phosphate sulfate (27-12-0-4) at 67 lbs/acre (75 kg/ha) of N. Respective yearly application rates for P and S were 29 and 10 lbs/acre (33 and 11 kg/ha).

Design of the study was completely random, resulting in eight replications of the following sequence of treatments:

1. Unfertilized/not covered
2. Unfertilized/covered
3. Fertilized/not covered
4. Fertilized/covered

Protection of half of the plots was done to determine growth responses of bitterbrush and understory vegetation and response of bitterbrush crude protein to fertilization in the absence of mule deer use. Comparison of fertilized/covered and fertilized/not covered treatments provided an estimate of the attractant effect of fertilization for mule deer.

In the fall of each year (1973-1976), cover of bitterbrush and associated shrubby species was measured on a 2 x 32.8 ft (0.6 m x 10 m) permanent belt transect that bisects each plot. Cover was determined as a vertical projection of foliar vegetation on to the soil surface expressed as a percentage of the surface covered.

At the same time, 50 random leaders of the current annual growth were clipped from bitterbrush on each plot. After these were measured, leaves and stems were oven dried at 70°C, separated, and ground in a Wiley mill to pass a 60 mesh screen. Samples were analyzed for total N (Bremner and Tabatabai 1972). For the 1974 collection, all eight replications of each treatment were analyzed. In the following 2 years, small samples from each replication were composited by treatment. Total N values were converted to crude protein using a conversion factor of 6.25 (Cook and others 1962).

Except for 1973, cover and biomass of herbaceous understory vegetation were measured in the spring. In 1973, these measurements were made prior to fertilization in the fall. Biomass of herbaceous species was determined each year by clipping 2 ft by 2 ft (0.6 m by 0.6 m) quadrats at two random locations within each plot. Different locations were clipped in each year.

Differences among treatments for cover of bitterbrush, other shrubs, and associated herbaceous species, leader length, understory biomass, and crude protein (in 1974) were evaluated by analysis of variance with a completely randomized design (Steele and Torrie 1960). The Duncan multiple range test was used to determine significant differences among individual treatments. The principal hypothesis was that fertilization would have no effect on cover, leader length, crude protein of bitterbrush, and biomass productivity and cover of understory vegetation.

RESULTS AND DISCUSSION

Comparisons of Soil Characteristics

Soil reaction, as measured by pH of areas beneath shrubs, was more basic (6.96) than open areas (6.66). This difference was highly significant (P = 0.01). Romney and others (1977) also found a tendency for higher pH in areas under desert shrubs than in bare areas, but Tiedemann and Klemmedson (1973) found no differences in pH of the surface 1.8 inches (4.5 cm) of soil between areas under mesquite (Prosopis juliflora [Swartz] DC) and adjacent open areas.

Higher levels of microbial activity and the resultant CO_2 generation would be expected to reduce pH in areas beneath shrubs compared to open areas. It appears, however, that cation input from litter through leaching and decomposition may be sufficient to displace $H+$ ions through mass action resulting in an increase (or no change) in pH. Leaching of plant tissue has been shown to remove up to 45 percent of cations such as calcium, magnesium, sodium, and potassium (Tukey and others 1958).

Total N was three times greater in soil from beneath bitterbrush shrubs than in open soils (0.12 percent compared to 0.04 percent). Total S and total C differences were similar. Total S under shrubs was 0.011 percent compared to 0.005 percent in open areas. Total C was more than twice as great under shrubs than openings (3.52 percent compared to 1.41 percent). These differences are highly significant ($P = 0.01$) and indicate that bitterbrush functions in a manner comparable to other desert shrubs in redistributing nutrients from open areas to areas beneath shrubs. Garcia-Moya and McKell (1970) and Tiedemann and Klemmedson (1973) observed that lateral roots of Larrea and Prosopis shrubs (respectively) deplete nutrients of surrounding open areas. Through deposition of leaves and other detritus to the zone beneath the canopy, islands of fertility are created. Symbiotic nitrogen fixation by bitterbrush (Wagle and Vlamis 1961) may also play a role in the N-enrichment patterns observed in the present study. However, the role of these fertile islands in successional development of shrub communities is at present not known.

In the case of bitterbrush in the present study, the N and S levels observed in openings are insufficient for adequate growth and development of many higher plant species. Even the levels of N and S under bitterbrush shrubs would be considered marginal for this climatic zone (Jenny 1930, 1941) and are at the lower end of concentrations observed in wildland soils in eastern Oregon and Washington (Geist and Strickler 1970; Tiedemann and Berndt 1972; Tiedemann and Klock 1977).

Soil Nutrient Availability

Yields (g/pot) of biomass in the nutrient availability trial for the check treatment (no added nutrients) were significantly less ($P = 0.05$) than yields of the full nutrient treatment (table 1). Yields of treatments from which N and S were deleted (N_0, S_0), but with P and K added to each were the same as the check treatment indicating limited availability of N and S in these soils. With addition of N and S (P_0 and K_0 treatments), yields were increased to the same level as the full nutrient treatment. Availabilities of P and K were apparently sufficient since deletion of these caused no reductions compared to the full nutrient treatment.

Table 1.--Response of biomass yields to nutrient treatments in the greenhouse pot trial.

S_0 (NPK added)	Check (No nutrients added)	N_0 (PKS added)	P_0 (NKS added)	Full (NPKS added)	K_0 (NPS added)
- - - - - - - -	- - - - - - - - - - - -	- - - - - - -	g/pot - - - - - -	- - - - - - - - -	- - - - - - - -
2.26	2.48	2.48	4.23	4.59	4.63

Values (g/pot) with the same underline are not significantly different at P = 0.05.

Relative yields of S, N, P, and K were 49, 54, 92, and 101 percent, respectively. Jenny and others (1950) developed a relationship of relative yields of N and P from pot trials to the percent of field tests responding to added N and P for agriculture settings in California. For N, a relative yield of 30 percent denoted a soil low in N which would likely give a field response to added N. Relative yields of N above 50 percent indicated high N supplies and little chance of a field response to N fertilization. For P, the relative yield for a fertilizer response was 30 percent or less. There appears to be no comparable information for wildland settings. Comparison of RY values of N established by Jenny and others (1950) suggest little chance for a response of bitterbrush and associated species to fertilization (they did not develop RY values for S). However, considering the extremely low levels of N and S in surface soils and the RY levels of N and S in the 50 percent range, there is a strong potential for a response in the field setting to added N and S.

The very high relative yields of P and K indicate little possibility for a fertilizer response to addition of these elements.

Bitterbrush Responses to Fertilization

Since the response of bitterbrush to fertilization is the central focus of this paper, the data for associated shrub species is not presented. These generally made up less than 10 percent of the total shrub cover and were too variable for a valid statistical analysis of their response.

There were no significant differences among treatments for bitterbrush vegetative cover in any year. Cover varied widely from a low of about 16 percent in 1973 (average of treatments) to a high of 32 percent in 1974 and 1976 (fig. 1). Fluctuations in cover were a reflection of the August through February precipitation.

The current annual leader growth (average among treatments) also varied widely from 3.5 to 7.3 inches (9.0 cm to 18.6 cm) (table 2). As with cover, leader growth was responsive to August through February precipitation (fig. 1). This period's precipitation in 1973 was 4.8 inches (12.1 cm) and leader length (average of treatments) was 3.6 inches (9.2 cm). In 1974, leader length more than doubled to 7.3 inches (18.6 cm) in response to a precipitation increase to 10.4 inches (26.3 cm). The relationship to precipitation trends for bitterbrush cover and current leader growth may prove to be a useful tool in the future for predicting forage productivity in bitterbrush habitats where most of the precipitation occurs in the winter. Kindschy (1982) has shown a positive relationship between bitterbrush productivity and the current crop year precipitation (September 1 to June 30). Bitterbrush leader production (inches) = $0.593 x -1.67$ ($r=.622$).

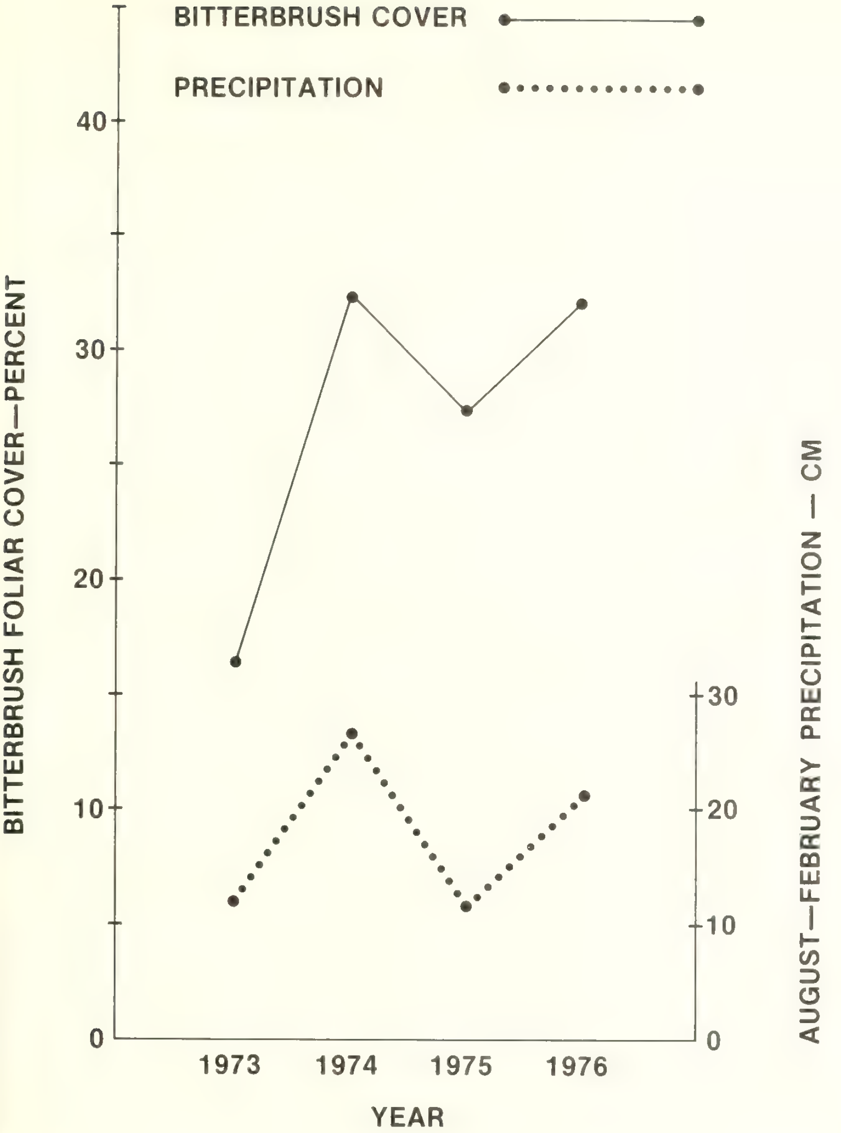

Figure 1.--Relationship of bitterbrush cover to August-February precipitation.

Table 2.--Length of 50 random bitterbrush leaders following fertilization and protection treatments.

	Unfertilized not covered	Unfertilized covered	Fertilized not covered	Fertilized covered	Mean	F-test
			cm[1]			
Prefertilization						
1973	9.0	8.9	9.3	9.5	9.2	NS
Postfertilization						
1974[2]	19.6^a	19.8^a	15.8^b	19.4^a	18.6	*
1975	10.1	8.7	8.5	8.8	9.0	NS
1976	9.1	8.9	9.1	9.8	9.2	NS

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[1] Inches = cm divided by 2.54

[2] Values with differing superscript letters are significantly different at P=0.05 according to the Duncan multiple range test.

*Significant at P=0.05.

NS = not significant

In 1974 there was a significant difference in length of leaders among treatments (table 2). The Duncan multiple range test revealed that average leader length of the fertilized/not covered treatment was significantly lower than the other treatments. In 1975 and 1976, there were no significant differences in leader length among treatments.

Current annual leader growth was measured in the fall to assess the growth response to fertilization; differences in leader length among treatments probably represent spring and summer use by mule deer. Shorter leader lengths on the fertilized/not covered plot are indicative of an attractant effect of fertilization similar to that observed by Bayoumi and Smith (1976) and reported in a summary paper by Duvall (1970). Greater use of the current annual leader growth on the fertilized/not covered plot in 1974 is probably also related to the "nutritional wisdom" of the animals, whereby they select forage that best provides for their physiological needs (Ivins 1952). It is not known why this apparent attractant effect of fertilization did not occur in 1975 and 1976. Perhaps in 1974, mule deer were confined to this part of their range for a protracted period into summer because of excessive snow depths at higher elevations. Snowfall in 1974 was more than twice as great as in 1975 and about 40 percent greater than 1976. The more open winters of 1975 and 1976 may have permitted earlier access to higher elevations so that spring and summer use of bitterbrush was less than in 1974.

Analysis of crude protein in leaves and stems of bitterbrush did not reveal any striking responses to treatments (table 3). For leaves, however, there was a strong variation among years ranging from 8.1 to 12. 9 percent (average of treatments). Reasons for this difference are not known, particularly since the lowest values occurred after three applications of fertilizer. Crude protein values for stems in 1976 are also notable. Values for fertilized plots are lower than those for unfertilized plots in 1976. The reason for this is also not known.

Table 3.--Percent of crude protein in bitterbrush leaves and stems following three annual fall applications of 27-12-0-4 (NPKS) fertilizer at 247 lb/acre/year (278 kg/ha/year).

	Unfertilized not covered	Unfertilized covered	Fertilized not covered	Fertilized covered	Mean	F-test
			percent			
Leaves:						
1974	12.7	10.8	13.6	11.9	12.2	NS
1975	14.5	11.8	12.6	12.9	12.9	NT
1976	8.1	7.2	9.1	7.9	8.1	NT
Stems:						
1974	6.5	7.1	6.3	7.2	6.7	NS
1975	7.8	7.5	6.2	7.6	7.2	NT
1976	7.1	7.1	4.6	5.1	5.9	NT

NS = Not significant.
NT = No statistical test.

Herbaceous Understory Vegetation Responses

Response of herbaceous understory species was the most striking effect of fertilization observed in this study. Cover and biomass measurements of the herbaceous understory prior to fertilization in 1973 were not significantly different among treatments (tables 4 and 5), indicating that the replications selected for treatment were reasonably uniform. Vegetative cover was more uniform among plots than biomass prior to application of fertilizer (table 4).

Table 4.--Response of herbaceous understory vegetation cover to three annual fall applications of 27-12-0-4 (NPKS) fertilizer at 247 lb/acre/year (278 kg/ha/year).

	Unfertilized not covered	Unfertilized covered	Fertilized not covered	Fertilized covered	F-test
	- - - - - - - - - - - - - -	- - percent cover- -	- - - - - - - -		
1973, fall	6.9	7.3	6.4	8.2	NS
1974, spring	17.8^{a}[1]	21.0^{a}	18.6^{a}	38.6^{b}	**
1975, spring	20.9^{a}	24.8^{a}	41.1^{b}	53.5^{b}	**
1976, spring	14.4^{a}	17.8^{ab}	30.8^{bc}	39.8^{cd}	**

** = Significant at P = 0.01.

NS = Not significant

[1] Values with different superscript letters are significantly different at P = 0.05.

On protected plots (fertilized/covered), fertilization increased cover and biomass of understory vegetation, 1974-1976, compared to both unfertilized treatments. In 1974 cover of the fertilized/not covered treatment was significantly less than that of the fertilized/covered treatment. The same response was observed for biomass in 1976 (table 5), but not for cover (table 4). Reduced cover in 1974 and reduced biomass in 1976 on the fertilized/not covered compared to the fertilized/covered treatment likely resulted from increased use of the fertilized forage similar to that observed for bitterbrush current annual leader growth.

The amounts of fertilizer N, P, and S potentially available for uptake by bitterbrush were determined by subtracting an estimated uptake by herbaceous understory vegetation from the amounts of each element applied. The differential herbage production between unfertilized/covered and fertilized/covered treatments (table 5) was used as the basis for this estimation. Concentration values of 1.6 percent total N and .26 percent total P in cheatgrass and bluebunch wheatgrass forage (Miller 1958) were used to convert herbage production values to uptake values for N and P. A value of .13 percent S in herbage was assigned based on the normal ratio of N:S in plant material of 12:1 (Allaway and Thompson 1966). The total production differential between the two treatments, 1974-1976, was 2,065 lb/acre (2,321 kg/ha). Resultant uptakes of N, P, and S during the 3 years were 33, 5, and 3 lb/acre (37, 6, and 3 kg/ha), respectively. These amounts are a relatively minor part of the total of 200, 88, and 29 lb/acre (225, 99, and 33 kg/ha) of N, P, and S applied. Therefore, most of the applied nutrients should have been available for uptake by bitterbrush.

Table 5.--Biomass of herbaceous understory vegetation in response to three annual fall applications of 27-12-0-4 (NPKS) fertilizer at 247 lb/acre/year (278 kg/ha/year) of N.

	Unfertilized not covered	Unfertilized covered	Fertilized not covered	Fertilized covered	F-Test
	- - - - - - - - - - - - -	- kg/ha[1]	- - - - - - - -	- - - - - - - -	
1973	$(477)^{a}$[2]	$(715)^{a}$	$(406)^{a}$	$(206)^{a}$	NS
1974	$(686)^{a}$	$(827)^{ab}$	$(1460)^{bc}$	$(1636)^{c}$	**
1975	$(709)^{a}$	$(839)^{a}$	$(1549)^{b}$	$(1781)^{b}$	*
1976	$(888)^{a}$	$(1005)^{a}$	$(968)^{a}$	$(1642)^{b}$	+

NS = not significant

** = significant at P = 0.01.

* = significant at P = 0.05.

+ = significant at P = 0.10

[1] lb/acre = kg/ha X 0.89

[2] Values with different superscript letters are significantly different at P = 0.05.

CONCLUSIONS

Results indicate that fertilization of bitterbrush habitats in the areas tested would not be effective for promoting growth or crude protein of the bitterbrush. These results contrast with the work of Leman and Pittack (see footnote 5) and with results of the study by Bayoumi and Smith (1976). Both of those studies showed that N was effective in promoting growth and increasing crude protein contents of bitterbrush. However, the lack of fertilizer response of bitterbrush was the same as observed by Klemmedson and Ferguson (1969). In their study, bitterbrush grown in surface soil derived from granitic parent material either did not respond or displayed reduced productivity to added N when P, K, and S were also added. They concluded that bitterbrush may not have a high demand for N or that it may be a true pioneering species from this standpoint. A later study (Klemmedson and Ferguson 1973) demonstrated a positive response of bitterbrush in granitic soils to additions of sulfur. Wagle and Vlamis (1961) found that bitterbrush responses to the pot trial technique of Jenny and others (1950) varied depending on the type of soil. In a basalt-derived soil, P was deficient for bitterbrush, but N was adequate. In a pumice soil the response was reversed. They related the differential N response to the presence of nitrogen fixing nodules. Plants grown in the pumice soil in which N was limiting for bitterbrush growth produced no root nodules.

The stands chosen for this study are representative of much of the bitterbrush habitat in the mid-Columbia region. The majority of shrubs would be categorized as mature or decadent. Leman and Pittack studied fertilization of shrubs in this class, but added a pruning treatment that was probably responsible for most of the growth response they observed. Work by Ferguson and Basile (1966) tends to support this conclusion. They observed that topping of old bitterbrush shrubs increased twig production by 9 times. On mature form class 1 and 2 shrubs Leman and Pittack obtained a marked growth response to fertilization. Bayoumi and Smith (1976) were not specific about the age and form class of shrubs they studied, but it appears from a photograph that these were mature class shrubs. In the present study, lack of growth and crude protein response of bitterbrush appears to be related to the decadent nature of the plants. Plant senescence involves changes in meristematic activity and mobilization of nutrients and substrates (Leopold and Kriedemann 1975). In the case of decadent, over-mature bitterbrush, age probably affects the ability of shrubs to generate new roots, thereby limiting their capability to use fertilizer elements. Since herbaceous understory utilized only a small portion of the fertilizer, sufficient added N, P, and S probably were available for shrub uptake.

Another possibility is that low levels of S in these soils limits the development of bitterbrush roots throughout the life of the plants--a condition that may accelerate the senescence process and lead to decadence. Wagle and Vlamis (1961) found that S deficiencies limited root development of bitterbrush in pumice soils. Additions of S at a late stage in the life of the plants may not be effective in overcoming effects of long-term S deficiencies on root development.

Even though fertilization did not improve bitterbrush production in this study, there are two aspects of the results that deserve emphasis. The attractant effect of fertilization, as indicated by increased use of the fertilized/not covered plot, may be a potentially valuable aid to the land manager in controlling wildlife movement and utilization patterns. Additional research must be conducted to verify this response over several years involving more extensive areas.

Increases in cover and biomass of understory vegetation with fertilization have important implications for erosion reduction and restoration of land stability. Fertilization at the rates in this study approximately doubled the protective vegetative cover afforded the soil surface. In areas with active erosion, such as those in the present study, fertilization appears to be an effective means of improving surface protection.

The relationships established in this study among bitterbrush, cover, leader length, and precipitation need to be studied in terms of actual productivity values in pounds per acre (kg/ha) to be of maximum use to the land manager for predicting amounts of forage that are potentially available for wintering mule deer.

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PUBLICATIONS

Allaway, W. H.; Thompson, J. F. Sulfur in the nutrition of plants and animals. Soil Sci. 101(4):240-247. 1966.

Bayoumi, Mohamed A.; Smith, Arthur D. Response of big game winter range vegetation to fertilization. J. Range Manage. 29:44-48. 1976.

Black, C. A.; Evans, D. D.; White, J. L.; and others. Methods of soils analysis. Part I. Agronomy No. 9. Madison, WI: American Society of Agronomy and American Society of Testing Materials; 1965. 802 p.

Bremner, J. M.; Tabatabai, M. A. Use of ammonia electrode for determination of ammonium in Kjeldahl analysis of soil. Commun. in Soil Sci. and Plant Analysis 3:159-165. 1972.

Burrell, Galen. Winter diets of mule deer in relation to bitterbrush abundance. J. Range Manage. 35:508-510. 1982.

Cook, C. W.; Biswell, H. H.; Clark, R. T.; and others. Basic problems and techniques in range research. Publ. No. 890. Washington, DC: National Academy of Sciences, Natural Research Council. 1962; 341 p.

Daubenmire, R. Steppe vegetation of Washington. Tech. Bull. 62. Pullman, WA: Washington Agriculture Experiment Station. 1970; 131 p.

Duvall, V. L. Manipulation of forage quality, objectives, procedures, and economic considerations. In: a research symposium. Misc. Publ. 1147. Washington, DC: U.S. Department of Agriculture, Forest Service; 1970; p. 19-31.

Ferguson, R. B.; Basile, Joseph V. Topping stimulates bitterbrush twig growth. J. Wildlife Manage. 30:839-841. 1966.

Franklin, J. F.; Dyrness, C. T. Natural vegetation of Oregon and Washington. Gen. Tech. Rep. PNW-8. U.S. Department of Agriculture, Forest Service. Portland, OR: Pacific Northwest Forest and Range Experiment Station. 1973.

Garcia-Moya, E.; McKell, C. M. Contribution of shrubs to the nitrogen economy of a desert-wash plant community. Ecology 51:81-88. 1970.

Geist, J. M.; Strickler, G. S. Chemical characteristics of some forest and grassland soils. I. Results from reference profile sampling on the Starkey Experimental Forest and Range. Res. Note PNW-137. U.S. Department of Agriculture, Forest Service. Portland, OR: Pacific Northwest Forest and Range Experiment Station. 1970.

Hitchcock, E. L.; Cronquist, A. Flora of the Pacific Northwest. University of Washington Press; 1973. 730 p.

Ivins, J. D. The relative palatability of herbage plants. J. Brit. Grassland Soc. 7:43-54. 1952.

Jenny, H. A study on the influences of climate upon the nitrogen and organic matter content of the soil. Res. Bull. 152. Missouri Agriculture Experiment Station; 1930. 66 p.

Jenny, H. Factors of soil formation. New York: McGraw-Hill Book; 1941. 281 p.

Jenny, H.; Vlamis, J.; Martin, W. E. Greenhouse assay of fertility of California soils. Hilgardia 20:1-8. 1950.

Kindschy, R. R. Effects of precipitation variance on annual growth of 14 species of browse shrubs in southeastern Oregon. J. Range Manage. 35:265-266. 1982.

Klemmedson, J. O.; Smith, J. G. Cheatgrass (Bromus tectorum L.) Bot. Rev. 2:226-262. 1964.

Klemmedson, J. O.; Ferguson, R. B. Response of bitterbrush seedlings to nitrogen and moisture on a granitic soil. Soil Sci. Soc. Amer. Proc. 33:962-966. 1969.

Klemmedson, J. O.; Ferguson, R. B. Effect of sulfur deficiency on yield and nitrogen content in bitterbrush (Purshia tridentata) seedlings on granitic soils. Soil Sci. Soc. Amer. 37:947-951. 1973.

Klock, G. O.; Geist, J. M.; Tiedemann, A. R. Erosion control fertilization--from pot study to field testing. Sulphur Inst. J. 7:7-10. 1971.

Klock, G. O.; Geist, J. M.; Tiedemann, A. R. Response of orchardgrass to sulphur in sulphur-coated urea. Sulphur Inst. J. 11:4-8. 1975.

Leopold, A. Carl; Kriedemann, Paul E. Plant growth and development. New York: McGraw Hill Book; 1975. 545 p.

McColley, Phillip D. Soil resource inventory, Wenatchee National Forest. U.S. Department of Agriculture, Forest Service. Wenatchee, WA: Pacific Northwest Region, Wenatchee National Forest; 1976. 276 p.

Miller, Donald F. Composition of cereal grains and forages. Publ. 585. Washington, DC: National Academy of Sciences, National Research Council; 1958. 663 p.

Patton, D. R.; Hall, J. M. Evaluating key areas by browse age and form class. J. Wildlife Manage. 30:476-480. 1966.

Romney, E. M.; Wallace, A.; Kaaz, H.; and others. Effect of shrubs on redistribution of mineral nutrients in zones near roots in the Mojave desert. In: the belowground ecosystem: a synthesis of plant-associated process. Science Series 26. Marshall, J. L. (ed.). Fort Collins, CO: Colorado St. Univ., Range Science Department. 1977:303-310.

Steele, R. G. D.; Torrie, J. H. Principles and procedures of statistics. New York: McGraw-Hill Book, 1960. 481 p.

Tiedemann, A. R. Soil properties and nutrient availability in tarweed communities of central Washington. J. Range Manage. 25:438-443. 1972.

Tiedemann, A. R.; Anderson, T. D. Rapid analysis of total sulphur in soils and plant material. Plant and Soil 35:197-200. 1971.

Tiedemann, A. R.; Berndt, H. W. Vegetation and soils of a 30-year deer and elk exclosure in central Washington. Northwest Science 46:59-66. 1972.

Tiedemann, A. R.; Klemmedson, J. O. Effect of mesquite on physical and chemical properties of the soil. J. Range Manage. 26:27-29. 1973.

Tiedemann, A. R.; Klock, G. O. Meeks Table Research Natural Area--reference sampling and habitat classification. Res. Pa. PNW-223. U.S. Department of Agriculture, Forest Service. Portland, OR: Pacific Northwest Forest and Range Experiment Station; 1977, 19 p.

Tukey, H. B., jr.; Tukey, H. B.; Wittmer, S. H. Loss of nutrients by foliar leaching as determined by radioisotopes. Proc. Am. Soc. Hortic. Sci. 71:496-506; 1958.

Wagle, R. F.; Vlamis, J. Nutrient deficiences in two bitterbrush soils. Ecology 42:745-752. 1961.

Section 7. Fire Relationships

A LITERATURE REVIEW OF THE FIRE RELATIONSHIPS OF ANTELOPE BITTERBRUSH[1]

Carol L. Rice[2]

ABSTRACT

The relationship of *Purshia tridentata* to fire is discussed through a review of the literature. The plant associations in which the species occurs and the fire frequencies of those associations are described. A presentation of the plant's adaptations to fire and factors affecting the response to fire follow. The management implications of these relationships are presented, including the possibility that prescribed fire may be used to enhance the management of this species.

PAST ROLE OF FIRE

Antelope bitterbrush occurs in a variety of plant associations. From the literature, these can be categorized into three zones: the ponderosa pine (*Pinus ponderosa* Dougl.), the steppe vegetation (sagebrush-grass [*Artemisia* L.]), and the juniper (*Juniperus* L.). Past fire frequencies can indicate how much fire the vegetativ community can tolerate without being replaced, and what role fire might play in the ecology of bitterbrush.

Ponderosa Pine Zone

The past role of fire in the ponderosa pine zone has been well documented. According to Weaver (1957), early observers reported that while various shrub specie were present in the pine forests in the 1880's and 1890's, they were never developed t the present size and density because of frequent and recurrent fires. He found the average interval between fires was 11 to 47 years. Arno (1976) reported the mean fir interval varying from 4 to 11 years in the climax ponderosa pine forests of the Bitterroot National Forest in Montana. Driver and others (1980) thought the mean fir interval of ponderosa pine stands was 7 to 10 years in Washington. In contrast, Wrig (1978) stated that the ponderosa pine-bitterbrush communities in west-central North America burned every 50 years or so. This hypothesis is based on his observations an current knowledge of the susceptibility of bitterbrush to fire.

Johnson and Smothers (1976) studied the fire history and ecology at the Lava Bed National Monument and reported that "early travelers to southern Oregon and northern California remarked on the parklike appearance of ponderosa pine in this region."

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[1] Paper presented at the Bitterbrush and Cliffrose Symposium, Salt Lake City, Utah, April 13-15, 1982.

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Today the forest is filled with an understory of mountain mahogany (Cercocarpus H.B.K. sp.) and bitterbrush. Although these were components of the original communities, frequent fires kept densities at a low level. They found the mean fire interval of the pine forest was quite frequent--a fire almost every 6 years.

Steppe Vegetation Zone

Franklin and Dyrness (1973) stated that fire and ungulate grazing in the steppe vegetation zone were apparently of limited importance in the Northwest before Europeans and their livestock arrived in the mid-1800's. Daubenmire (1970) (in Franklin and Dyrness 1973) says: "There is no evidence that the distribution of vegetation types or species in eastern Washington is related to the past use of fire." Wright and others (1979) noted that fire covered a large portion of the sagebrush-grass community in Yellowstone every 14 to 47 years; but, based on the vigorous response of horsebrush (Tetradymia canescens DC) to fire and the 30 years needed for it to decline, the probable frequency of fire would be about 50 years. They reasoned that if fires occurred every 20 to 25 years, many sagebrush-grass communities would have been dominated by horsebrush and rabbitbrush (Chrysothamnus Nutt. sp).

Juniper Zone

Wright and others (1979) reported that fire occurred every 10 to 30 years in the pinyon-(Pinus edulis Dougl.) juniper communities, and that fire kept junipers restricted to shallow, rocky soils and rough terrain. They remind us that the historic role of fire cannot be separated from the effects of drought and competition as the three play complementary roles in the distribution of vegetation.

Driscoll (1964) reported on a stand of bitterbrush in the juniper zone of central Oregon that had not been disturbed by man. Bitterbrush had a 9 percent shrub cover in the natural area, which constituted 40 percent cover of all perennial plants and 94 percent of the shrub cover. The plants were widely spaced (350/acre or 865/ha), restricted by soil types, averaged 5 ft (1.5 m) in height, and contained wide crowns. Driscoll also stated that wildfire appeared to have been a major factor in determining tree survival and distribution in the juniper-bitterbrush-Agropyron (Gaertn) association.

Young and Evans (1981) studied juniper-sagebrush stands in Lassen County, Calif., and reported that the most vigorous bitterbrush stands appeared to occur in old burns where juniper was reduced or eliminated.

In summary, the role of fire in habitats where bitterbrush is a component varies with vegetation zones. Fire occurring every 6 years or 50 years depending on the location, was important in the ponderosa pine zone. Fire does not appear to have been as frequent in the steppe vegetation zone, which has a mean fire interval as long as 50 years. Fire seems to have played a major role in the juniper zone, restricting distribution of tree species and other vegetation, and enhancing density of bitterbrush.

BITTERBRUSH AS A FUEL

The role of fire in a community is strongly influenced by its effects, which in turn is influenced by the fire behavior. Fuel is one manageable factor of those agents that determine fire behavior. Fuel characteristics may indicate season of fire, range of potential, fire intensity, and range of the rate of spread. Because any plant is a fuel, it is worthwhile to investigate bitterbrush as a fuel.

Some of the important characteristics concerning bitterbrush as a fuel are:

1. Available fuel loading (what is on the ground to burn).
2. The arrangement of fuel (horizontal and vertical continuity).
3. Distribution of diameter size classes of the available fuel loading.
4. Moisture content of the fuel.
5. Heat and ash content of the fuel (whether any volatile oils exist in high levels that might affect the fire behavior).

The fuel loading where bitterbrush occurs is generally light. Ponderosa pine forest communities where bitterbrush occurs probably have the heaviest loading because the pine produces much litter and contributes heavy fuels of larger diameters. However, Johnson and Smothers (1976) report that shrubs under ponderosa pine have the potential to greatly increase the available fuel loading. This, in turn, increases th likelihood of a conflagration that could destroy the entire community. In both the sagebrush-bitterbrush and juniper-bitterbrush communities, fuel loading is often so light that it will not carry a fire except under extreme fire weather conditions. Martin (1978) reported that fuels ranged from 1.4 to 4.3 tons/acre (3 137-9 633 kg/ha) (very light) in juniper associations and that the fuels were mostly the bunchgrasses, sagebrush, and bitterbrush. Meuggler and Stewart (1981) studied forage production (fuel production) of bitterbrush and found that average yearly production of the shrub component of the bitterbrush-Fescue scabrella (Torr.) habitat type (mainly bitterbrush was 670 lb/acre (123 kg/ha). This was a yearly gross production of fuels; there is no estimate of the proportion decomposed and eaten yearly. Bitterbrush itself does not produce much fuel.

The arrangement of fuels varies in bitterbrush in a number of ways. The fuel arrangement of the decumbent ecotype of bitterbrush is different from the columnar ecotypes. The low, spreading form would be more accessible to the flames. In addition, the fuel arrangements differ in plant crowns. The crown may be dense and compact if heavily grazed or browsed, or may be wide and open otherwise. Martin and Dell (1978) mentioned an example of how the arrangement of fuels affects fire behavio in Planning for Prescribed Burning in the Northwest: "The needle drape in the bitterbrush will cause each plant to flare up; burners should be cautioned about this Horizontally, the arrangement of fuel generated from bitterbrush is clumped, which is not conducive to fire spread, unless there are interspersed fuels such as grass, pine needles, or dense sagebrush.

The preponderance of dead fuel in bitterbrush itself is usually under 1/2 inch (1.2 cm) in diameter. The size, 1/4 inch (0.6 cm) or less, is considered "1-hour" fuel -- that is, the fuel reaches equilibrium with the atmosphere in 1 hour. In area where a high dead-to-live ratio in bitterbrush plants exists, dead fuels can influenc fire behavior to respond quickly to weather changes. However, because most are live fuels, the moisture in the plants would affect fire behavior to a greater extent. Li fuel moisture is typically highest during the spring and declines regularly until several inches of rainfall initiate an upward trend (Green 1981).

Nord and Countryman (1972) measured the moisture and ash content of nine shrub species in May 1971. They found the moisture content in bitterbrush foliage and stem to average 147 and 131 percent, respectively. Ash content is on the low side, but normal, at 3.8 percent of the foliage and stems. A high ash content tends to make th plant material less flammable.

Philpot (1969) found that the heat content of bitterbrush is average; thus, one would not expect explosive fires such as occur in chamise, which has a high ether extract content. As with other plants, the heat content of bitterbrush fluctuates wih the season, but, unlike many other plants, it decreases in summer. The heat content n spring averages 5,040 calories/gram, lowers to 4,600 calories/gram in summer, then rises to 5,010 calories/gram in the fall. Heat content changes the flammability, intensity, and rate of spread in fire. However, other factors are more important than heat content in determining fire behavior characteristics.

Adams (1980) reported that the fire behavior of prescribed burns on the Fort Rock Ranger District in Oregon in April and September was a function of the continuity of the fuel bed and the age and condition of shrubs--the younger stands (which tend to be discontinuous) did not support fire. Older stands (40 years plus) of the sagebrush-bitterbrush-bunchgrass plant community had consistent characteristics: flame length was 5 to 15 ft (1.5 to 4.6 m), intensity was 18-2,000 BTU/ft (kilocalories/meter-sec), and the rate of spread was 660 to 1320 ft/hr (201 to 402 m/hr). He reported that the fires were either nonburning or severe, with little intermediate fire behavior. Flammability appeared to be correlated to plant and stand age and presence of associated grasses, with the fuels being sensitive to weather changes.

RESPONSE OF BITTERBRUSH TO FIRE

Adams (1980) suggested that bitterbrush evolved in a fire climate. Mutch (1970) suggested that if a species were favored by burning, it would adapt to be flammable. Flammability can be enhanced by a concentration of fine fuels, low moisture content, high dead-to-live ratios, and high volatile oil content. Bitterbrush is mainly small diameter, its moisture content on the low side, its volatile oil content not extreme, and its dead-to-live ratio varies. Bitterbrush could respond to fire as do other plant species by reseeding into the site, surviving the fire and growing (freed from plant competition from other vegetation for some years), sprouting from adventitious roots just below the soil surface (sprout from the stem), or being completely eliminated from the site. Bitterbrush has, in fact, responded in all four of these ways.

Factors Affecting Sprouting Capability

The ability to sprout is only one adaptation for plant survival after fire. However, it is the most important adaptation in vegetation where bitterbrush occurs. Sprouting allows for better competition for moisture. It also seems to be the biggest determinant as to how long it takes for forage production to return to preburn state, and in some cases, whether bitterbrush would remain on the site at all. Why bitterbrush does or does not sprout has been variously attributed to fire intensity, genetic capabilities (different ecotypes), soil moisture and soil type, season of burn, and other factors.

FIRE INTENSITY

Blaisdell (1953) studied the ecological effects of planned burning on the sagebrush-grass range of the Upper Snake River in Idaho. He found that sprouting response of bitterbrush varied with fire intensity. Out of 800 bitterbrush plants, 49 percent sprouted after a light burn, 43 percent after a moderate burn, and 19 percent after a heavy burn. Bitterbrush was able to make a recovery (because of the sprouting that took place) after 34 growing seasons, but was still far below production of unburned sites. Blaisdell also reported that many bitterbrush plants sprouted soon after burning, made rapid growth, and gained dominance within 9 years.

Driver and others (1980) burned bitterbrush in a ponderosa pine-grass-bitterbrush habitat type with a light prescribed fire in the early spring in Washington and observed a 40 to 100 percent resprouting response. In a high intensity fire in an area where thinning debris had been piled and burned, they observed no sprouting. They concluded that bitterbrush can resprout following low intensity fires.

GENETIC CAPABILITIES

Sprouting in bitterbrush is affected by location within its range probably as a result of genetic variability. Wright and others (1979), in reviewing various ecotype that exist in bitterbrush, stated that the decumbent ecotype generally resprouts after fire or top removal; this aggressive species is capable of revegetating severely disturbed areas after planting. The columnar forms on granitic soils in Idaho will generally resprout after fire or top removal, but resprouting seems to be dependent on fire intensity and soil moisture. Other ecotypes are more severely damaged by fire. Their review concluded that cool, spring burns in decumbent forms result in low mortality and high resprouting, but low seedling establishment. In fall burns, with good soil moisture, resprouting and layering occur in the decumbent ecotypes. They generalized that while fire harms the columnar ecotype more than the decumbent type, cool fall fires are least damaging to the columnar ecotypes. Fire harms bitterbrush more in fine-textured and calcareous soils than on coarse textured and wel drained soils. Spring burning enhances sprouting.

Because one ecotype can be prevalent over large areas, previous studies that have explained variation in sprouting of bitterbrush by its location may have actually been observing a prevalent ecotype. Countryman and Cornelius (1957), finding that bitterbrush did not sprout on a northeastern California plateau after a moderate fire in August 1949, stated that a notable feature of burned plots was the complete loss of bitterbrush while, in contrast, bitterbrush was 91 percent of the forage on unburned plots. Nord (1965) noted that antelope bitterbrush is known to sprout in several locations in California. He reported that the only area outside California with frequent and abundant sprouting is eastern Idaho. Nord also reported that because so moisture affected the degree to which bitterbrush stems were damaged, it was importan in determining the degree of sprouting in a stand. When a rainstorm put out a fire o water was used to prevent fire from spreading, heavy sprouting occurred. Intensity i not a crucial factor, he states. Good sprouting is also most likely to develop along drainage channels, or in soils with good soil moisture retention. Where soil moistur was low, no sprouting occurred, regardless of the destruction suffered by the plant.

Sherman and Chilcote (1972) reported that resprouting of bitterbrush is infreque in central Oregon. Five of 2,052 bitterbrush plants were sprouts, and 13 of those plants that had been cut below the soil surface had adventitious roots. Thus, it reproduced largely from seed, They noted, however, that although bitterbrush didn't sprout, because of a good adjacent seed source their plots were rapidly repopulated after fire, as indicated by a fire scar.

OTHER FACTORS

Environmental factors--Driscoll (1963) suggests that sprouting is not only controlled by genetics but also environmental factors, as well as intensity of the burn. In plots he studied in the ponderosa pine-bitterbrush-fescue and sagebrush-bitterbrush zones, he reported little difference between fire intensity an degree of sprouting. Where plants layered, the plant sprouted at the point of layering, not at the parent plant. Sprouting always occurred 2 to 3 inches (5 to 7. cm) below the soil surface. The frequency of sprouting was associated with soil texture and aspect. On north slopes, in loose coarse soils without pumice or cinder bitterbrush had the highest sprouting with 80 percent. In fine textured stony soils, 1 percent sprouted. Where cinders and pumice were abundant, sprouting was minimal because, being porous, they transfer heat deeper, injuring the plant base more severe

Season of burn--Adams (1980) stated in work done on the Fort Rock Ranger Distri in Oregon that bitterbrush sprouted 80 percent on a spring burn and 20 percent on a fall burn. As previously noted, others have also observed a difference in sprouting in bitterbrush with spring, summer, and fall burns.

Carbohydrate reserve cycle--A large percentage of sprouts die 1 year after a fire. Klebenow and others (1976) reported that although sprouting was adequate on a site mortality after 1 year was widespread. One explanation rests in the carbohydrate reserve cycle in plants. Menke and Trlica (1981) reported that this cycle was a good screening tool for assessing relative effects of defoliation possibly by fire on different plant species. Plants that replenish reserves rapidly in the spring and minimize the time in low reserve status were least affected by defoliation.

Bitterbrush had a typical "V" shaped carbohydrate reserve cycle as shown in figure 1 (Menke and Trlica 1981). Burning when reserves in the taproot are lowest could most drastically affect the plant's ability to sprout. Lowest reserves occurred in the stem in May and June and in the taproot in late June to mid-July. Bitterbrush is unusual in that it doesn't completely replenish carbohydrate reserves until the fruit is fully developed, whereas most plants replenish those reserves somewhat earlier. No one has studied the possible variations in the carbohydrate reserve cycle in different ecotypes of bitterbrush, or documented the phenological stage of plant development when burned, but this approach could help anticipate when sprouting is likely to be most successful in order to optimize the time of the burn.

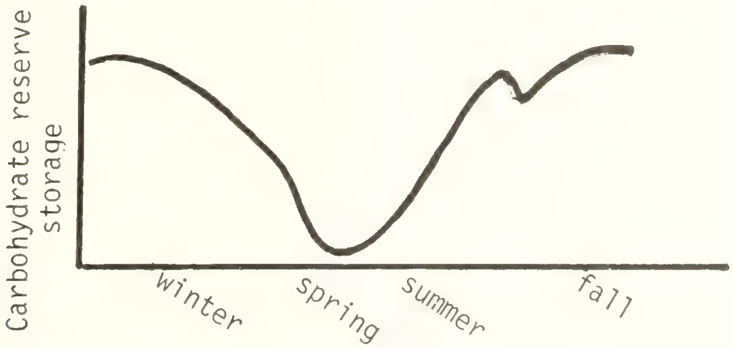

Figure 1. Graph showing carbohydrate reserve storage during winter, spring, summer, and fall.

Factors Affecting Capability to Reestablish by Seed

Blaisdell (1953) stated that part of the recovery of bitterbrush, even where they sprout, comes from new plants established by seed, especially on high intensity fires where most of the old plants were killed.

Driver and others (1980), in developing their hypothesis of the role of fire in bitterbrush, reasoned that older plants (75 to 90 years) have maintained productive capacity for a long time through some mechanism, such as fire resistance, vegetative regrowth, or sprouting. They found that after an intense fire, where thinning debris had been piled and burned, bitterbrush and snowbrush ceanothus (Ceanothus velutinus Dougl.) seedlings were the only shrubs present. Grass was absent from the burn site, even though it was dominant before the fire. They concluded that bitterbrush can function as a pioneer plant in intense fires due to lack of competition from grass, and that the seedling mechanism works when there are infrequent intense fires in the vegetation type.

Sherman and Chilcote (1972) studied the distribution of bitterbrush in central Oregon in the open sagebrush and forest communities by measuring distances of rodent caches from fire-scarred trees. They found the amount of litter on the ground was extremely important in determining the extent bitterbrush seedlings would appear on the site. The amount of litter was inversely proportional to the distance of caches from the fire-scarred tree used as a plot center. Rodents had a positive effect on seedling numbers because of their seed caches. Caches generally occurred where litter was light, and these locations resulted in higher seedling survival because of favorable pH, moisture, and other factors. Fire occurrence caused extensive seedling establishment. Seedling establishment declined gradually thereafter until another fir occurred.

Nord (1965) reported that seedling establishment varies considerably from year to year and from site to site even though precipitation, soils, and density are comparable. The soil must be moist to the depth of seeds in the fall, winter, and early spring for good seedling establishment. Nord also suggested that an alleopathy of associated plant's litter explains why the presence of litter and duff do not favor bitterbrush. He adds that sagebrush acts as a nurse plant for bitterbrush seedlings because of shade and other factors.

Wright and others (1979) reported that seedlings from the decumbent forms appear to be more competitive than from upright forms. Germination is generally higher in th low growing ecotype, and seedlings are favored by fall burning.

MANAGEMENT IMPLICATIONS

The perpetuation of healthy bitterbrush stands is a difficult management situation. Franklin and Dyrness (1973), building on Sherman's (1966) observations, stated that bitterbrush is the most readily eliminated of the common shrubs, although on some sites fire reduction, consequent competition, and increases in canopy density may have the same effect. This conclusion places the land manager in a dilemma on us of fire in bitterbrush on tree-covered sites. Light to moderate fires may enhance bitterbrush stands (Martin and Dell 1978; Sherman and Chilcote 1972; Driver and other 1980); however, they can generally be achieved only under prescribed conditions.

While bitterbrush has evolved under a fire regime, land management practices ove the last 120 years have led to a general stagnation of bitterbrush stands in the West Fires up to the mid-1800's were more frequent and resulted in grass ranges and pine forests both with widely spaced shrubs, including bitterbrush. Cattle grazing resulted in an increase in shrub cover because of a decrease in the fine fuels of grass litter and in the competition factor of grass in the understory. Bitterbrush cover increase, contributing to the increase in deer herds in the West.

More aggressive fire control measures that were introduced during the early 1900s have affected browse ranges in two ways. When fire control was effective, the shrub stands became decadent, with an increased average age of plants and with sagebrush becoming dominant. When more intense fires than occurred in grass stands of the precattle era occurred in these older browse stands, bitterbrush underwent severely reduced productive capacity.

Sherman and Chilcote (1972) concluded in their study of spatial and chronologica patterns that bitterbrush is not a fire-resistant, but a fire-dependent species. Bitterbrush needs to have the litter cleared to enhance rodent caching. Under natura conditions, it is likely bitterbrush would occupy this niche indefinitely. They stated that fire control practices change the scenario. With intense fires because of fuel buildup, destruction of all plants is likely. If fire does not occur bitterbrush habitat will deteriorate and may be lost from portions of its present range.

In contrast, Weaver (1957) stated that bitterbrush's present distribution and extreme density over portions of the Klamath region of California are the result of human fire exclusion efforts over the last 40 to 50 years. Summerfield (1976) stated that bitterbrush is one the species most sensitive to fire in Nevada. If there is 15 to 25 percent composition by weight of bitterbrush on these sites, these areas should not be burned.

Leopold (1950) noted: "Along the lower fringe of ponderosa pine on the Truckee River, logging and recurrent fires have stimulated extensive growths of bitterbrush, on which a fine deer herd now winters. But, a few miles down the canyon toward more arid Reno, fire seems to wipe out both bitterbrush and sagebrush, giving rise to almost pure stands of cheatgrass. One cannot generalize, therefore, about where and when a given technique may be beneficial." This statement holds true today. Of the many factors affecting bitterbrush's response to fire, four are unalterable. Managers should know what is on the site and what influences these four factors bear on bitterbrush's response. The factors are the ecotypes present, what vegetative competition exists, soil texture, and soil moisture. Two factors helping determine fire's effect that can be manipulated by the potential burner are the season of burn and burn intensity.

Determining why bitterbrush reacts to fire as it does may depend on related ecological factors. For instance, intensity, soil texture, and soil moisture may all be related to how much damage is done to the stem; the question is what to use as an indicator to regulate damage. The genetic theory for explaining bitterbrush sprouting is uncompromising in that either the plants have or do not have adventitious buds. The percentage of buds in plant populations may vary, but if the population does not have specialized buds, bitterbrush will not sprout from the base even in the best conditions.

The literature displays many viewpoints of fire and bitterbrush. The author concludes that fire can and should be used in communities in which bitterbrush occurs under narrow conditions. Needing further research are the conditions necessary to meet range, wildlife, watershed, and silviculture objectives with prescribed fire.

PUBLICATIONS CITED

Adams, Glenn R. Results of range/wildlife prescribed burning on the Fort Rock Ranger District in central Oregon. R-6 Fuels Management Notes, Aviation and Fire Management, Portland, OR: Pacific Northwest Region, September 24 and December 1, 1980. 1980.

Arno, S. F. The historical role of fire on the Bitterroot National Forest. INT-187. Res. Paper. Ogden, UT U.S. Department of Agriculture, Forest Service Intermountain Forest and Range Experiment Station, 1976. 29 p.

Blaisdell, James P. Ecological effects of planned burning of sagebrush grass range on the Upper Snake River Plains. Technical Bulletin 1075. U.S. department of Agriculture, Forest Service 1953. 39 p.

Clark, Roger. A bibliography of bitterbrush (Purshia tridentata [Pursh] DC). Annotated from 1967 to 1978. Station Bulletin. 640, Corvallis, OR: Agriculture Experiment Station, Oregon State University, 1979. 18 p.

Countryman, C. M. Cornelius. D. R. Some effects of fire on a perennial range type. J. Range Manage. 19:39-41. 1951.

Daubenmire, R. Steppe vegetation of Washington. Washington Agriculture Experimental Station Technical Bulletin 62. 1970. 131 p.

Driscoll, R. S. Sprouting bitterbrush in central Oregon. Ecology 44:820-821. 1963.

Driscoll, R. S. A relict area in central Oregon juniper zone. Ecology 45:345-353. 1964.

Driver, C. H.; Winston: V. A. G. Goehle. H. F. The fire ecology of bitterbrush - a proposed hypothesis. In Proceedings of the sixth conference on fire and forest meteorology. P. 204-208. Martin, R., R. Edmonds, D. Faulkner, J. Harrington, D. Fuquay, B. Stocks, and S. Barr (eds.). Society of American Foresters, Washington, DC 1980. 304 p.

Franklin, J. F.; Dyrness. C. T. Natural vegetation of Oregon and Washington. General Technical Report PNW-8. Portland, OR: U.S. Department of Agriculture, Forest Service. Pacific Northwest Forest and Range Experiment Station, 1973. 417 p.

Green, L. R. Burning by prescription in chaparral. Forest Service General Technical Report, PSW-51. Berkeley, CA. U.S. Department of Agriculture, Forest Service. Pacific Southwest Forest and Range Experiment Station, 1981. 36 p.

Johnson, A. H.; Smothers. G. A. Fire history and ecology, Lava Beds National Monument. In Tall timbers fire ecology conference 15 P. 103-115. Tallahassee, Fla. Tall Timbers Research Station, 1976. 279 p.

Klebenow, D. A. Beall; Bruner. A; Controlled fire as a management tool in the pinyon-juniper woodland. Nevada Annual Progress Report, Reno, NV University of Nevada, 1976. 73 p.

Leopold, Starker. Deer in relation to plant succession. J. Forestry 48:675-678. 1950.

Martin, R.; and Dell, J. Planning for prescribed burning in the inland Northwest. General Technical Report PNW-76. Portland, OR: U.S. Department of Agriculture, Forest Service. PNW-76. Pacific Northwest Forest and Range Experiment Station, 1978. 67 p.

Martin, R. E. Fire manipulation and effect in western juniper (Juniperus occidentalis Hook). In Proceedings of the western juniper ecology and management workshop. P. 121-136. General Technical Report PNW-74. Portland, Oregon. U.S. Department of Agriculture Forest Service Pacific Northwest Forest and Range Experiment Station, 1978. 177 p.

Menke, J. W.; Trlica. M. J. Carbohydrate reserve, phenology and growth cycles of nine Colorado range species. J. Range Manage. 34:269-276. 1981.

Meuggler, W. F.; Stewart. L. W. Forage production on important rangeland habitat types in western Montana. J. Range Manage 34:347-353. 1981.

Mutch, R. W. Wildland forest and ecosystems-a hypothesis. Ecology 51:146-1051. 1970.

Nord, E. C. Autecology of bitterbrush in California. Ecol. Monogr. 35:307-334. 1965.

Nord, E. C., and C. M. Countryman. Fire relationships. In Wildland Shrubs-their biology and utilization. McKell, C. M., J. P. Blaisdell, and

J. R. Goodin (eds.). Gen. Tech. Rep. INT-1., Ogden, UT: U.S. Department of Agriculture Forest Service Intermountain Forest and Range Experiment Station, 1972. 494 p.

Philpot, C. W. Seasonal changes in heat content and ether extractive content of chamise. Research Paper INT-61. Ogden, UT: U.S. Department of Agriculture Forest Service. Intermountain Forest and Range Experiment Station, 1969. 10 p.

Sherman, R. J. Spatial and chronological patterns of *Purshia tridentata* as influenced by *Pinus ponderosa* overstory. Unpublished M.S. thesis on file at Oregon State University, Corvallis. 81 p. 1966.

Sherman, R. J.; Chilcote, W. W. Spatial and chronological patterns of *Purshia tridentata* as influenced by ponderosa pine. Ecology 53:294-298. 1972.

Summerfield, H. B., Jr. Effects of prescribed burning on watershed conditions. *In* Symposium of use of prescribed burning in western woodland and range ecosystems. Logan, UT: Utah Agriculture Experiment Station, P. 43-46. 1976. 90 p.

Weaver, H. Effects of prescribed burning in second growth ponderosa pine. J. Forestry 44:823-826. 1957.

Wright, H. A. The effect of fire on vegetation in ponderosa pine forests. Publ. T-9-199. Texas Tech. Univ. Range and Wildlife Information series No. 2., Lubbock, TX: College of Agriculture Sciences. Texas Tech. University, 1978. 21 p.

Wright, H. A., Neuenschwander, L; Britton, C. The role and use of fire in sagebrush-grass and pinyon-juniper plant communities-a state-of-the-art review. Gen. Tech. Rep. INT-58. Ogden, UT. U.S. Department of Agriculture, Forest Service. Intermountain Forest and Range Experiment Station, 1979. 48 p.

Young, J. A.; Evans, R. Demography and fire history of a western juniper stand. J. Range Manage. 34:501-506. 1981.

FACTORS AFFECTING ANTELOPE BITTERBRUSH REESTABLISHMENT FOLLOWING FIRE[1]

Robert E. Martin and Charles H. Driver[2]

ABSTRACT

Successful sprouting of bitterbrush after fire is controlled by such factors as plant genetics and morphology, plant age, competition, soil type, burning conditions, fuel load, past history, browsing pressure, and others. Seedling establishment depends on such factors as seed supply, rodent population, site, and others. Discussion centers on assessing the effects of fire on bitterbrush stands.

INTRODUCTION

Antelope bitterbrush (Purshia tridentata (Pursh) DC.) response to fire is of vital concern to land managers because the shrub is considered an important browse plant for big game throughout most of its range. Generally, investigators indicate fire is detrimental to bitterbrush in both the short- and long-term. However, bitterbrush is often abundant in systems where fire is known to have occurred frequently. Some investigators indicate burning with a cool, moist soil will give high sprouting percentage, while others state that no burning conditions give satisfactory bitterbrush regeneration after fire.

Such contradictions have led us to try to resolve the differences by considering the many factors affecting bitterbrush regeneration. Our grouping of the factors is for convenience of discussion. Many of the factors are interrelated, and we'll attempt to indicate this.

We'll cite only those papers that relate to factors being discussed. For a more complete review of literature on bitterbrush, the reader should consult Basile (1967) and Clark and Britton (1979).

SPROUTING

Many factors are important in determining whether or not bitterbrush sprouting will occur. While sprouting occurs readily on some areas, it may never in other areas because of genetic or other factors. In some cases, more frequent fire under more moderate conditions may be important in improving sprouting.

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[1] Paper presented at the Bitterbrush and Cliffrose Symposium in Salt Lake City, Utah, April 13-15, 1982.

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Genetics and Morphology

There appears to be a strong genetic influence in the ability of bitterbrush to sprout. Papers in this proceedings that cite the genetic variability in bitterbrush include: Davis, Driver, Edgerton and others, McArthur and others, Shaw, and Winward. Most of these studies, however, were not concerned with genetic variability in regard to response following fire.

Blaisdell (1950, 1953) pointed out that the ability of a plant to sprout is important in its rapid recovery after burning, and bitterbrush was intermediate in its ability to sprout. Wagle (1958) noted a great deal of variability in sprouting bitterbrush. In California, bitterbrush sprouting ranged from nonexistent to frequent on various burns, but was more common in the zone where hybridization occurred with desert bitterbrush, a good sprouter.

Bitterbrush sprouted anywhere from 3 weeks to 13 months after burning, or after top removal from dormant buds wholly or partly encircling the stem at ground level, or from a callus of meristematic tissue formed beneath the bark after treatment (Blaisdell and Mueggler 1956). The sprouts after burning were from buds protected by soil. The variability in bud location, callus formation, and time of sprouting might indicate genetic variability.

Driver and others (1980) observed that a large number of bitterbrush plants were sprouting from what appeared to be a lignotuber, according to the terminology of Daubenmire (1974). The lignotubers are swellings in the main stem at or just below the ground line. Because this characteristic has not been reported by other investigators, it may only be characteristic of bitterbrush in the area of central Washington where it was observed.

Morphology of bitterbrush appears linked to its sprouting ability. Decumbent forms are known to layer more readily than columnar forms, and location of adventitious buds around base may differ.[3]

Phenological Condition

The phenological condition of a plant at the time its top is removed, whether by ire or cutting, could greatly affect both its ability to sprout and the vigor of the prouts. Food reserves of the plants generally are depleted rapidly during the fast arly growing period when photosynthesis is unable to keep pace with utilization. hus, removal of the top, or killing the top with fire, could leave the plant low in ood reserves and with a less vigorous sprouting capability.

Several investigators have measured the levels of food reserves in plants hroughout the year. Most measured total available carbohydrate (TAC) or total nstructural carbohydrate (TNC). McConnell and Garrison (1966) found TAC dropped n all bitterbrush plant parts during leaf formation, flowering, rapid growth, and eed formation. As growth rate slackened, TAC began to increase throughout the plants. They felt bitterbrush carbohydrate metabolism would be harmed most by herbage removal during the depletion phase of the carbohydrate cycle between vernalization and early seed formation stages.

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[3] Robert G. Clark and Carlton M. Britton, Texas Tech University, Lubbock. ersonal communication.

TAC was less affected than were herbage yield and morphological characteristics of antelope bitterbrush, and all were affected most by defoliation of bitterbrush during late spring and fruit development or seed shatter stages (Menke 1974). Multiple severe defoliations in one year were quite harmful. Buwai's (1975) results also showed bitterbrush herbage yield and vigor to be affected more than TNC. The plants were most affected by defoliations toward the end of the growing season. Plants that received three defoliations had greatly reduced herbage yield, but remained in good vigor. No plants with three or six defoliations had recovered after 14 or 26 months rest from grazing.

Trlica and others (1977) indicated plants defoliated during the fruit development phenological stage had shorter twigs than did those at other times. Herbage yields, vigor, and basal stem TNC levels were still lower in defoliated plant 14 and 26 months after defoliation than in nondefoliated plants.

Crude protein and apparent digestibility rose while crude fiber and crude fat dropped somewhat during the active growing period and fruit development of bitterbrus in central Oregon (Hickman 1975). He did not comment on the implication for survival after fire or crown removal.

On the applied side, Blaisdell and Mueggler (1956) noted that spring burning yielded more sprouting than burning in summer or fall, yet clipping date had little effect on sprouting. Phenological condition could be involved, but they felt other factors were more important. Jensen and others (1972) indicated that bitterbrush grazed by sheep even moderately during seed ripening will not produce more growth that year. Bitterbrush that were heavily grazed at that time appeared to lack vigor Wagstaff (1980) reported that a 1975 summer wildfire eliminated almost all bitterbru from a site. It is possible that the phenological condition contributed to that bitterbrush loss.

Plant Age

Very young and very old plants of a species may not sprout well. Our observations are that seedlings less than 5 years old and bitterbrush greater than 40 to 60 years of age do not sprout well. Perhaps the young seedlings have not yet developed the food reserves or layers to protect adventitious buds. Perhaps they've not yet developed the capability of forming the buds or meristematic callus, as it is called by Blaisdell and Mueggler (1956). Very old plants often seem to lack the vigor necessary to develop sprouts. This could be caused by any number of physiological factors, but it is likely a factor of the lack of food reserves in an already decadent plant.

Blaisdell and Mueggler (1956) point out that higher sprouting occurred after either burning or clipping of bitterbrush sprouts or new plants less than 15 years old than occurred on older plants; 7 to 10 clipped plants under 15 years old sprouted, whereas only 24 to 50 clipped plants older than 15 years sprouted.

The productivity of bitterbrush increased until an age of 60 to 70 years but then declined (McConnell and Smith 1977) in early heavy grazing and moderate late grazing. Whether or not this growth ability is also reflected in sprouting ability is not known.

Clark (1979) found no relationship between sprouting and age. One 92-year-old lant sprouted after being severed 5.9 inches (15 cm) above the ground lines.

Our own experience indicates that bitterbrush seedlings, say under 5 years, and lder, decadent plants, perhaps older than 40 to 60 years, do not sprout.

Competition

Competition with other plants both before and after the fire will affect the bility of bitterbrush to reestablish itself. Before fire, competition will affect he general vigor of the plant, reducing its ability to sprout.

Hormay (1943) pointed out that bitterbrush is intolerant of shade and does est in forest openings and on slopes below the pine forest. Bitterbrush seedlings oming after fire often lost out in competition with cheatgrass (Bromus tectorum L.). e noted only two fires in California where sprouting had occurred and felt sprouting as not a main source of regeneration for bitterbrush.

Hubbard and others (1962) explored mortality in a mature bitterbrush stand where ompetition was a main source of mortality. The bitterbrush was in competition with tself and with crested wheatgrass (Agropyron desertorum Fisch.) They recommended ot over 2,200 bitterbrush plants per acre (5,434 plants/ha), or about a 4.5 ft 1.4 m) spacing, for a good site. They cited a personal communication from E. C. ord where he recorded an average stocking of 778 plants per acre (1,922 plants/ha) ith a maximum of 1,420 plants(3,507 plants/ha). Sanderson and others (1963) felt his maximum might be too few in artificially seeded areas.

Sanderson and others (1963) checked the perennial grass competition by weeding ut all plants except bitterbrush. Very significant responses in leader length were ecorded for bitterbrush plants in both good and poor condition. The grass ompetition affected vigor as expressed by leader length, which could in turn affect ortality.

Western juniper (Juniperus occidentalis Hook.) and bunchgrasses are important ompetitors of bitterbrush in the Devil's Garden area of northern California Hubbard 1965). Reduction of either competitor would leave more moisture and utrients for bitterbrush, thus improving its vigor. McConnell and Smith (1965, 970a) recorded an increase in grasses, forbs, and shrubs following thinning of onderosa pine (Pinus ponderosa Dougl.) stands in eastern Washington. Antelope itterbrush yield increased about 2 lbs/acre (2.2 kg/ha) for each 1 ft (0.3 m) ncrease in spacing and 1 lb/acre (1.1 kg/ha) for each 1 percent decrease in canopy. tal shrub (mostly bitterbrush) increment was 45 lb/acre (50.5 kg/ha), or a ,100 percent increase, at 18.7 and 26.4 ft (5.7 to 8.1 m) spacings compared to lbs/acre (16.8 kg/ha), or 166 percent increase, at 13.2 ft (4.0 m) spacing. e original stand was 2,800 trees/acre (6,916/ha) or an average spacing of 3.9 ft .2 m).

Partial cutting of a lodgepole pine (Pinus contorta Dougl.) stand from .3 to 20.5 ft^2/acre (21.0 to 4.7 m^2/ha) basal area in a central Oregon pumice te resulted in an average of 108 percent increase in twig length on mature tterbrush plants (Edgerton and others 1975). They felt numbers of twigs were also creased, but had no supporting data.

Stuth and Winward (1976) recorded the effects on bitterbrush of clearcut gging in lodgepole pine in central Oregon. Although 43 percent of the plants were st in logging, the leader length and general vigor of the remaining plants creased considerably.

Burning of bitterbrush in southeastern Idaho did not increase its yield because of large numbers of plants killed, low sprouting success, and competition from other plants (Murray, this proceedings).

Soil Type

Soil type can affect bitterbrush sprouting after fire especially through coarseness of the surface soil. Because sprouting occurs from adventitious buds or meristematic callus at or just below the soil surface, a soil that reduces heat transfer to these areas should enhance sprouting. Loose, pebbly soils may allow the fibrous bark and other organic matter in the surface soil to burn, thus causing more heating of the plant below ground. Finer soils may retain more surface soil moisture through capillarity, thus reducing combustion and temperature rise of the plant tissues just below ground line.

Nord (1959, 1965) reported antelope bitterbrush growing on soils developed from a wide range of parent materials including granitic, rhyolitic basaltic, pumiceous or sedimentary sandstone, and shale rock. He reports that it grows best on coarse textured soils that are well drained, very permeable, and slightly acid. It gives way to other plants on heavier textured, poorly drained, or basic soils. He indicate sprouting is related to the degree of damage at or just below ground line.

Driscoll (1963) reported the best sprouting of bitterbrush following two wildfires in central Oregon was on coarse-textured, nonstony soils without cinders or pumice. Fine-textured, stony soils have low sprouting. The least sprouting was where cinders or pumice were present.

Giunta and others (1978) maintain that sprouting is better on finer textured soils. Our casual observation indicates we are getting less sprouting following fire where soils are very coarse and pebbly. This is especially noticeable on the coarse "popcorn" pumice sites where we have burned.

Soil Moisture

High surface soil moisture has been reported by many investigators as necessary for or improving bitterbrush sprouting (Blaisdell 1953; Blaisdell and Mueggler 1956; Nord 1965; Pechanec and others 1965; Wright and Britton 1976; Martin and Dell 1978; Martin and Johnson 1979; Adams 1980; Olson and others 1981; Volland and Dell 1981; and Murray, this proceedings). Early spring and late fall are recommended for burning, when the soil is cool (Martin and Dell 1978; Martin and Johnson 1979; Adams 1980; Murray, this proceedings). The lower soil temperature requires more heat to be added to bring the protected plant tissue to the lethal temperature. Wildfires, which generally occur during the summer when soils are warm and dry, may account for the low sprouting afterwards.

Burning Conditions

Conditions under which burns are conducted may also affect bitterbrush sprouting. Fuel moisture, particularly that in the duff (H layer) if present, is closely related to soil moisture, and may contribute to sprouting response. The condition of the site after burning was used by Blaisdell (1950, 1953) to classify the "intensity"[4] as light, moderate, or heavy. Sprouting was inversely related to intensity, but even on the light burns less than 50 percent of the bitterbrush sprouted; 43 percent sprouted on the moderate burns, and 19 percent on the heavy burns.

Blaisdell and Mueggler (1956) reported that burned bitterbrush sprouted less readily than bitterbrush with complete tops removed. Since date of top removal did not vary with season, they believe the "intensity" of burn is what caused better sprouting in the spring. An August fire had a high rate of sprouting, but the sprouting occurred where water was sprayed to control spread of the fire.

Mueggler and Blaisdell (1958) reported a late August fire to be very damaging to bitterbrush. Countryman and Cornelius (1957) reported complete loss of bitterbrush for 6 years following an August wildfire in northern California.

Nord (1959) reported only one fire in California, an early January burn, where sprouting occurred on more than 25 percent of the bitterbrush, and in 1965 he stated that conditions during burning are important. Pechanec and others (1965) reported that in eastern Idaho and parts of Utah, high percentages of bitterbrush have sprouted after light burning. Wagstaff (1980) reported no bitterbrush sprouting following a summer wildfire in Utah.

Prescription conditions and variable fire effects on bitterbrush based on timing and conditions during burning were mentioned by Martin and Dell (1978), Martin and Johnson (1979), and Olson and others (1981) for areas in central Oregon and northern California. Highest sprouting at Lava Beds National Monument followed a late fall burn where duff had a high fuel moisture so that little of it was consumed (Martin, this proceedings).

Driver and others (1980) gave data on bitterbrush sprouting following a spring burn in central Washington. Similarly, Adams (1980) observed 80 percent sprouting of bitterbrush following a spring burn versus 20 percent sprouting after a fall burn. He cited burning conditions as one of the factors contributing to the difference.

More recently, Laven and Omi (this proceedings) and Murray (this proceedings) cited spring burning conditions as being most favorable for bitterbrush resprouting.

History

What has happened on a site in the past might influence the sprouting of bitterbrush. Over a long time, frequent fire might cause genetic selection of plants for those with better capability to sprout. In the short term, frequent fire might enhance sprouting by keeping fuel loads down or maintaining plant vigor.

Blaisdell and Mueggler (1956) noted that bitterbrush sprouting following a 1953 burn was better on a site previously burned in 1939 than on an unburned site regardless of the date of burning. They speculated the reasons might be burn "intensity," greater ability of younger plants to sprout, or even genetic differences.

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[4] "Intensity" as used by Blaisdell is what many today refer to as "severity." We would prefer to use terms such as "fuel consumption" or "heat load," both of which could be measured or calculated, as indicators of the amount of heat supplied to the base of the plant. Intensity is technically the rate of heat release per unit of fire front (Byram 1959), and may or may not be related to the heat delivered to the base of the plant.

In a hypothesis, Driver and others (1980) pointed out that antelope bitterbrush, to be a dominant member of the plant community, should exhibit characteristics that insure its survival and perpetuation in such habitat environments. They used the ponderosa pine-pinegrass (Calamogrostis rubescens Buckl.)-bluebunch wheatgrass (Agropyron spicatum [Pursh] Scribn. & Smith)-bitterbrush habitats of central Washington as an example. Since these habitat types have a high fire frequency and bitterbrush is common, they concluded that bitterbrush must have mechanisms to cope with fire.

Fuel Load

The amount of fuel on a site can be a factor in bitterbrush sprouting after fire, although this is generally not mentioned in the literature. The fuel load is probably also related to competition, especially pine, and perhaps the length of time since fire and plant age. We have observed that sprouting of bitterbrush is low in the pine stands of central Oregon and northern California (Martin, this proceedings, even when these are burned with cool, moist soil and duff.

Browsing Pressure

Browsing pressure before and after fire can affect the ability of antelope bitterbrush to sprout and of the sprouts to survive. Some browsing appears to maintain plant vigor, but excessive or repeated browsing can be detrimental. Considered along with browsing will be grazing by domestic livestock, defoliation by insects, and cutting.

Hormay (1943) observed that plants weakened by previous grazing or caterpillar infestation may be seriously damaged or killed by a single heavy defoliation. Plants not previously weakened may recover quickly after a heavy attack by caterpillars, and 50 percent defoliation prevents flowering the next year.

Moderate clipping or topping of bitterbrush tends to enhance twig growth or crown characteristics (Garrison 1953; Ferguson and Basile 1966; Lesperance and others 1970; Ferguson 1972a; Trlica and others 1977). Heavy defoliation, browsing or clipping, or repeated clipping can harm plants and reduce forage (Hubbard 1965; Nord 1965; Menke 1974; Buwai 1975; McConnell and Smith 1977).

Ferguson (1968) noted that browsed young bitterbrush remained smaller than protected plants and had a slightly lower survival rate. Browsing one-third to one-half of the annual growth increased mortality. However, mechanically removing one-third to one-half of the bitterbrush canopy did not cause mortality (Ferguson 1972a). Twig production was stimulated by topping.

Jensen and others (1972) have shown sheep grazing does not decrease winter browse for wildlife provided the grazing is done before rapid twig elongation in the spring. Grazing later in the year used browse that would have been available for the coming winter.

McConnell and Smith (1977) indicated that heavy early-season grazing produces greater current twig yield per plant than does moderate late-season grazing. The heavy early-season grazing produces more mortality, however.

SEEDLING ESTABLISHMENT

Establishment of plants from seedlings is often the main way bitterbrush regenerates. In some areas, sprouting will be poor or absent following fire, regardless of conditions, and establishment from seed is necessary. Artificial seeding and planting is used in many areas where bitterbrush has been lost or was not present.

Seed Supply

An ample source of seed is a critical factor for seedling establishment of any species. Natural seed production has been discussed by only a few investigators; more have dealt with losses and distribution of seed.

Hormay (1943) stated that bitterbrush reproduces mainly from seed. Heavy seed crops on bitterbrush are a relatively infrequent occurrence in Utah, according to Giunta and others (1978).

Rodent Population

Rodents are important in the dissemination and destruction of seeds and may also destroy seedlings once established. Most bitterbrush seedlings develop from rodent seed caches (Hormay 1943; Nord 1959 and 1965; Hubbard 1965; West 1968; Sherman and Chilcote 1972; Giunta and others 1978; Evans and others, this proceedings). Many authors point out that successful seedling years depend on having a good seed year combined with a relatively low number of small mammals so that some cached seed are left for germination.

Rodents may transport the seed up to 1,000 ft (304.8 m) (Nord 1965). West (1968) reports that up to 90 percent of bitterbrush seedlings develop in clusters and estimates that 50 percent of the shrubs that develop may result from small mammal plantings. Other mammals and birds may also transport seed, and migratory Indians may at one time have accounted for long-distance movement of bitterbrush seed because it was used for medicinal purposes (Nord 1965).

Rodents cache the seed for later use. If rodent populations are high enough so seed production does not exceed their needs, essentially no cached seeds are left for seedling establishment (Hubbard 1965).

Rodents may also damage bitterbrush seedlings. Mice, and perhaps other rodents, rob seed spots[5] planted in the fall (Holmgren and Basile 1956). Meadow mice (Microtus montanus) severely damaged bitterbrush by girdling in northeastern California and Oregon in the late 1950's (Hubbard and McKeever 1961).

Site

Quality of a site in relation to the strains of bitterbrush is important to good bitterbrush seedling establishment. Although many abiotic and biotic factors enter into site quality, we'll primarily consider moisture, nutrients, and macro- and microclimatic conditions.

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[5] A seed spot is the location where one or more (usually more) seeds have been planted. Usually two or more seed spots may be located close together in a single scalped area.

Many investigators mention site, most often in connection with artificial regeneration. Hormay (1943) and Nord (1965) mentioned site in terms of natural and artificial regeneration. Giunta and others (1978) pointed out site factors, particularly moisture and winter conditioning temperatures, as being important factors. Soil moisture and soil surface temperature are also important in bitterbrush seedling establishment (Ferguson 1972b).

Burning Conditions

The conditions under which wildfires or prescribed burns occur can have an effect on bitterbrush seedling establishment. Blaisdell (1950) reported that the number of bitterbrush seedlings varied inversely with the "intensity" of a prescribed burn. Sherman and Chilcot (1972) indicated that rodents prefer to cache seeds in mineral soil, so burning must remove the duff. Driver and others (1980) observed good bitterbrush seeding where debris piles had burned out, which left ash and mineral soil and removed competition. They pointed out that infrequent, more severe fires may lead to more bitterbrush seedling establishment.

Plant Competition

Competition with other plants for moisture, nutrients, and light is important to bitterbrush seedling establishment. Serious competitors may be grasses, forbs, shrubs, or trees.

Depletion of soil moisture by competing vegetation was strongly related to bitterbrush seedling growth and mortality (Hubbard 1956). Heavy competition from native vegetation and crested wheatgrass was compared with plots weeded the first year and third year. After 3 years, plants with no competition were five times as tall as those under heavy competition and suffered only one-third the mortality.

Sanderson (1962) recorded 88 percent bitterbrush seedling survival in a rototille area versus 4 percent in an undisturbed area during a year of low precipitation. Bitterbrush responded to thinning of ponderosa pine stands in Washington (McConnell and Smith 1965, 1970a).

Percent survival of seedlings in a seedling spot was directly and strongly related to the number of seedlings (Ferguson 1962; Ferguson and Basile 1967). Thus, intraspecific competition was less important than the many factors that may help one or more of the seedlings in a group to survive.

Dealy (1970) showed that release from competition improved crown cover of 4-year-old bitterbrush more than its height growth. Protection from browsing was more effective than release from competition, but the combination of the two treatments was much more effective than either treatment alone.

Dietz and others (1980) showed that seeded bitterbrush survive two and a half times better after 10 years on an old burn site than in an open ponderosa pine stand. Growth was also better on the old burn site.

Bitterbrush seedlings have become established where slash accumulations have burned out, eliminating herbaceous vegetation for several years (Driver and others 1980).

Browsing Pressure

Browsing of bitterbrush seedlings by domestic livestock or wildlife reduces growth and survival. Animals may browse or graze in different ways, but excessive pressure can be very harmful. Proper browsing on adequately established plants can be stimulatory.

Lightly grazed pasture had a significantly higher density of bitterbrush plants than did a heavily grazed pasture (McConnell and Smith 1970b). Dealy (1970) indicated that protection from browsing significantly increased height and crown cover of 4-year-old bitterbrush seedlings. Monsen (this proceedings) has shown bitterbrush seedlings to establish in sites protected from grazing, and Martin (this proceedings) has shown four burn sites with heavy grazing to have significantly fewer bitterbrush seedlings than other burn units.

We have observed, but not measured, many young bitterbrush seedling groups that were completely or partly clipped off by either deer or cattle in partial or clearcut ponderosa pine areas after slash disposal.

INSECTS AND DISEASES

Insects and diseases may affect any phase of the bitterbrush life cycle. Some species may kill plants or reduce the vigor of young or old plants, making them susceptible to other agents. Others may reduce flowering or viable seed production or destroy seed or young seedlings. A better understanding of the insects and diseases affecting bitterbrush stands is needed, especially in connection with various patterns of manipulation and use.

Grasshoppers damage bitterbrush seedlings (Holmgren 1956). Edgerton and others (this proceedings) described the differential preference of grasshoppers for various provenances of bitterbrush. Hubbard (1956) described the destruction of bitterbrush seedlings by cutworms and wireworms, which destroy the cotyledons and roots, respectively.

Krebill (1972) compiled an annotated list of diseases for bitterbrush and other western shrubs, and Furniss and Krebill (1972) discussed the effects of insects and diseases on western shrubs. Furniss (this proceedings) discusses insect associates of bitterbrush, and Scholten (this proceedings) mentions insect problems in establishing bitterbrush in a wildlife management area.

ARTIFICIAL SEEDING AND PLANTING

Bitterbrush establishment following fire is presently dependent upon artificial seeding or planting in some areas. Few or no bitterbrush have been present or are left following fire, thus making artificial regeneration necessary.

Seed orchards and provenance studies have been established in many areas to provide seed. These are not without problems, as described by Edgerton and others, Shaw, VanEpps and Christensen, and Alder (all in this proceedings). But production of seeds or seedlings is generally successful. Guidelines for artificially regenerating bitterbrush stands or factors affecting success have been given by Hormay (1943), Nord (1956), Sanderson and Hubbard (1961), Plummer and others (1968), Dealy (1970), Steven and others (1974), Dietz and others (1980), and by Carpenter, Monsen, and Scholten (all in this proceedings).

SUMMARY

Successful regeneration of bitterbrush following fire is dependent on many factors. There is much overlap between the needs for sprouting of old plants versus natural seedling establishment, but each has unique requirements.

Sprouting is dependent on many factors. Some plants apparently are genetically not inclined to sprout whereas others have developed lignotubers from which sprouts emerge. Season of the year during which fires occur doesn't appear to be as important in obtaining sprouts as is a cool, moist soil condition. Whether lack of sprouting following fire during seed set and shatter is a phenological condition or due to lack of soil moisture has not been resolved.

Plant age and competition appear to affect sprouting ability, as both can affect general plant health and vigor. The degree to which these are responsible for sprouting capability again has not been determined. Plants in timbered areas have displayed less sprouting than nearby stands in the open. Animal browsing and pests as well as diseases can affect plant health and also alter sprouting capability.

The amount of fuel and burning conditions appear to change sprouting capability, but these factors have not been separated from other factors. Generally, fuel buildup will be greater in timber stands, thus confounding fuel load with tree competition.

A cool moist soil is a primary factor aiding bitterbrush sprouting. This factor alone will not cause good sprouting; some other critical factors may not be present.

Human protection of some stands to the point where they are old and decadent, where excessive fuel has accumulated, plant competition has developed, or the plants have not developed sprouting capability, has actually led to bitterbrush stands that are more susceptible to fire.

Natural seedling establishment following fire depends on seed supply, rodent population, site conditions in critical seedling years, plant competition, burning conditions, and browsing pressure. Generally, a good year to get seedlings started requires an excellent seed crop, a proper balance of rodents to cache the seed but not use it all, and a growing season in which soil moisture is not depleted too quickly. Plant competition and site conditions are factors in soil moisture depletion. Freezing and excessive heat may also be critical site factors. Burning conditions that destroy plant competition and create a good ash and mineral seedbed can aid establishment. Finally, excessive browsing and grazing by domestic livestock or wildlife can contribute to mortality or retard growth of bitterbrush seedlings.

PUBLICATIONS CITED

Adams, Glen R. Results of range/wildlife prescribed burning on the Fort Rock Ranger District in central Oregon. R-6 Fuels Management Notes. Portland, OR: U.S. Department of Agriculture, Forest Service, Region 6; 1980. 6 p.

Basile, J. V. An annotated bibliography of bitterbrush (Purshia tridentata Pursh) DC.). Res. Pap. INT-44. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1967. 27 p.

Blaisdell, James P. Effects of controlled burning on bitterbrush on the Upper Snake River Plains. Res. Pap. 20. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1950. 3 p.

Blaisdell, James P. Ecological effects of planned burning of sagebrush-grass range on the Upper Snake River Plains. Tech. Bull. 1075. U.S. Department of Agriculture, Forest Service; 1953. 39 p.

Blaisdell, James P.; Mueggler, Walter F. Sprouting of bitterbrush (Purshia tridentata) following burning or top removal. Ecol. 32(2): 365-370; 1956.

Buwai, M. Plant vigor, herbage yield, and total nonstructural carbohydrates of several range species as influenced by defoliation treatments and rest periods. Diss. Abs. 35: 1532; 1975.

Byram, George M. Fire behavior. In: Forest fire: control and use. New York, NY: McGraw-Hill Book Company; 1959.

Clark, Robert G. Seasonal response of bitterbrush to burning and clipping in eastern Oregon. Corvallis, OR: Oregon State University; 1979. 109 p. M.S. thesis.

Clark, Robert G.; Britton, Carlton M. A bibliography of bitterbrush (Purshia tridentata (Pursh) DC.) annotated from 1967 to 1978. Sta. Bull. 640. Corvallis, OR: Oregon State University Agricultural Experiment Station; 1979. 18 p.

Countryman, Clive M.; Cornelius, Donald R. Some effects of fire on a perennial range type. J. Range Manage. 10(1): 39-41; 1957.

Daubenmire, R. F. Plants and environment. A textbook of antecology. 3d ed. New York: John Wiley and Sons, Inc.; 1974.

Dealy, J. E. Survival and growth of bitterbrush on the Silver Lake deer winter range in central Oregon. Res. Note PNW-133. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1970. 5 p.

Dietz, Donald R.; Uresk, Daniel W.; Messner, Harold E.; McEwen, Lowell C. Establishment, survival, and growth of selected browse species in a ponderosa pine forest. Res. Pap. RM-219. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station; 1980.

Driscoll, Richard S. Sprouting bitterbrush in central Oregon. Ecol. 44(4): 820-821; 1963.

Driver, Charles H.; Winston, Valerie A.; Goehle, Henry F. The fire ecology of bitterbrush--a proposed hypothesis. In: Proceedings, Sixth conference on fire and forest meteorology; Washington, DC: Society of American Foresters; 1980: 204-208.

Edgerton, P. J.; McConnell, B. R.; Smith, J. G. Initial response of bitterbrush to disturbance by logging and slash disposal in a lodgepole pine forest. J. Range Manage. 28: 112-114; 1975.

Furniss, M. M.; Krebill, R. G. Insects and diseases of shrubs on western big game ranges. In: Wildland shrubs--their biology and utilization. Gen. Tech. Rep. INT-1. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1972. 218-226.

Garrison, George A. Annual fluctuation in production of some eastern Oregon and Washington shrubs. J. Range Manage. 6(2): 117-121; 1953.

Giunta, Bruce C.; Stevens, Richard; Jurgensen, Kent R.; Plummer, A. Perry. Antelope bitterbrush. Publ. 78-12. Utah Division of Wildlife Research; 1978: 48.

Hickman, O.E. Seasonal trends in the nutritive content of important range forage species near Silver Lake, Oregon. Res. Pap. PNW-187. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1975. 32 p.

Holmgren, Ralph C. Competition between annuals and young bitterbrush (Purshia tridentata) in Idaho. Ecol. 37(2): 370-377; 1956.

Holmgren, Ralph C.; Basile, Joseph V. Range revegetation and deer on the Payette. Idaho Wildlife Reve. 9(2): 10-13; 1956.

Ferguson, Robert B. Growth of single bitterbrush plants vs. multiple groups established by direct seeding. Res. Note 90. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station

Ferguson, R. B. Survival and growth of young bitterbrush browsed by deer. J. Wildl. Manage. 32: 769-772; 1968.

Ferguson, R. B. Bitterbrush topping: shrub response and cost factors. Res. Pap. INT-125. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1972a. 11 p.

Ferguson, R. B. Bitterbrush seedling establishment as influenced by soil moisture and soil surface temperature. J. Range Manage. 25: 47-49; 1972b.

Ferguson, Robert B.; Basile, Joseph V. Topping stimulates bitterbrush twig growth. J. Wildl. Manage. 30(4): 839-841; 1966.

Ferguson, Robert B.; Basile, Joseph V. Effect of seedling numbers on bitterbrush survival. J. Range Manage. 20(6): 380-382; 1967.

Furniss, M. M.; Krebill, R. G. Insects and diseases of shrubs on western big game ranges. In: Wildland shrubs--their biology and utilization. Gen. Tech. Rep. INT-1. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1972. 218-226 p.

Garrison, George A. Annual fluctuation in production of some eastern Oregon and Washington shrubs. J. Range Manage. 6(2): 117-121; 1953.

Giunta, Bruce C.; Stevens, Richard; Jurgensen, Kent R.; Plummer, A. Perry. Antelope bitterbrush. Utah Division of Wildlife Research Publication No. 78-12; 1978. 48 p.

Hickman, O. E. Seasonal trends in the nutritive content of important range forage species near Silver Lake, Oregon. Res. Pap. PNW-187. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1975. 32 p.

Holmgren, Ralph C. Competition between annuals and young bitterbrush (Purshia tridentata) in Idaho. Ecol. 37(2): 370-377; 1956.

Holmgren, Ralph C.; Basile, Joseph V. Range revegetation and deer on the Payette. Idaho Wildlife Reve. 9(2): 10-13; 1956.

Hormay, August L. Bitterbrush in California. Res. Note 34. Berkeley, CA: U.S. Department of Agriculture, Forest Service, California Forest and Range Experiment Station; 1943. 13 p.

Hubbard, R. L. The effects of plant competition on the growth and survival of bitterbrush seedlings. Res. Note 109, Berkeley, CA: U.S. Department of Agriculture, Forest Service, California Forest and Range Experiment Station; 1956. 9 p.

Hubbard, Richard L. The Devil's Garden deer range...what we need to know. Outdoor California 4(26): 4-5; 1965.

Hubbard, Richard L.; McKeever, Sturgis. Meadow mouse girdling--another cause of death of reseeded bitterbrush plants. Ecol. 43(1): 198; 1961.

Hubbard, Richard L.; Zusman, Pinhas; Sanderson, H. Reed. Bitterbrush stocking and minimum spacing with crested wheatgrass. California Fish and Game 48(3): 203-208; 1962.

Jensen, C. H.; Smith, A. D.; Scotter, G. W. Guidelines for grazing sheep on rangelands used by big game in winter. J. Range Manage. 25: 346-352; 1972.

Krebill, R. G. Preliminary annotated list of diseases of shrubs on western game ranges. Res. Note INT-156. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1972. 8 p.

Lesperance, A. L.; Tueller, P. T.; Bohman, V. R. Symposium on pasture methods for maximum production in beef cattle: competitive use of the range forage resource. J. Animal Science 30: 115-121; 1970.

Martin, Robert E.; Dell, John D. Planning for prescribed burning in the Inland Northwest. Gen. Tech. Rep. PNW-76. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1978. 67 p.

Martin, Robert E.; Johnson, Arlen H. Fire management of Lava Beds National Monument. In: Proceedings First conference on scientific research in the National Parks. Washington, DC: U.S. Park Service; 1979. Vol. 2: 1209-1217.

McConnell, B. R.; Garrison, G. A. Seasonal variations of available carbohydrates in bitterbrush. J. Wildl. Manage. 30(1): 168-172; 1966.

McConnell, Burt R.; Smith, Justin G. Understory response three years after thinning pine. J. Range Manage. 18(3): 129-132; 1965.

McConnell, B. R.; Smith, J. G. Response of understory vegetation to ponderosa pine thinning in eastern Washington. J. Range Manage. 23: 208-212; 1970a.

McConnell, B. R.; Smith, J. G. Some effects of grazing intensity on bitterbrush dispersion. J. Range Manage. 23: 92-94; 1970b.

McConnell, B. R.; Smith, J. G. Influence of grazing on age-yield interactions in bitterbrush. J. Range Manage. 30: 91-93; 1977.

Menke, J. W. Effects of defoliation on carbohydrate reserves, vigor, and herbage yield for several important Colorado range species. Diss. Abstr. 35: 632; 1974.

Mueggler, Walter F.; Blaisdell, James P. Effects on associated species of burning, rotobeating, spraying and railing sagebrush. J. Range Manage. 11(2): 61-66; 1958.

Nord, E. E. Quick testing bitterbrush seed viability. J. Range Manage. 9: 193-194; 1956.

Nord, Eamor C. Bitterbrush ecology--some recent findings. Res. Note 148. Berkeley, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station; 1959. 8 p.

Nord, Eamor C. Autecology of bitterbrush in California. Ecol. Monogr. 35(3): 307-334; 1965.

Olson, Craig M.; Martin, Robert E.; Johnson, Arlen H. Fire effects on vegetation in sagebrush-grass and ponderosa pine communities. In: Proceedings Second conference on scientific research in the National Parks. San Francisco, CA: U.S. Park Service; 1981. Vol. 10: 375-388.

Pechanec, Joseph F.; Plummer, A. Perry; Robertson, Joseph H.; Hull, A. C. Jr. Sagebrush control on rangelands. Agric. Handb. 227. Washington, DC: U.S. Department of Agriculture; 1965. 40 p.

Plummer, A. P.; Christensen, D. R.; Monsen, S. B. Restoring big-game range in Utah. Utah Division Fish and Game Publ. 68-3, Ephraim; 1968: 183.

Sanderson, H. Reed. Survival of rodent cached bitterbrush seed. Res. Note 211. Berkeley, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station; 1962. 3 p.

Sanderson, H. Reed; Hubbard, Richard L. Bitterbrush seed spotting on wildfire burns. Res. Note 192. Berkeley, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station; 1961. 7 p.

Sanderson, H. Reed; Hubbard, Richard L.; Seegrist, Donald W. Effects of grass competition on bitterbrush: second-year report. Res. Note PSW-26. Berkeley: CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station; 1963. 7 p.

Sherman, R. J.; Chilcote, W. W. Spatial and chronological patterns of Purshia tridentata as influenced by Pinus ponderosa. Ecol. 53: 294-298; 1972.

Stevens, Richard A.; Plummer, A. Perry; Jensen, Chester E.; Giunta, Bruce C. Site productivity classification for selected species on winter big game ranges of Utah. Res. Pap. INT-158. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1974. 24 p.

Stuth, J. W.; Winward, A. H. Logging impacts on bitterbrush in the lodgepole pine-pumice region of central Oregon. J. Range Manage. 29: 453-456; 1976.

Trlica, M. J.; Buwai, M.; Menke, J. W. Effects of rest following defoliations on the recovery of several range species. J. Range Manage. 30: 21-27; 1977.

Volland, Leonard A.; Dell, John D. Fire effects on Pacific Northwest forest and range vegetation. Portland, OR: U.S. Department of Agriculture, Forest Service, R-6; 1981. 23 p.

Wagle, Robert Fay. Early growth in bitterbrush and its relation to environment. Berkeley: University of California; 1958. 271 p. Ph. D. thesis.

Wagstaff, Fred J. Impact of the 1975 Wallsburg fire on antelope bitterbrush (Purshia tridentata). The Great Basin Naturalist 40(4): 299-302; 1980.

West, N. E. Rodent-influenced establishment of ponderosa pine and bitterbrush seedlings in central Oregon. Ecol. 49: 1009-1011; 1968.

Wright, H. A.; Britton, C. M. Fire effects on vegetation in western rangeland communities. In: Use of prescribed burning in western woodland and range ecosystems: Proceedings of a symposium. Logan, UT: Utah Agricultural Experiment Station; 1976: 35-41.

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Bitterbrush and cliffrose are perhaps the most widely managed shrubs in Western North America. This proceedings of 27 papers is a collection of our current knowledge on research and management of bitterbrush, cliffrose, and other rosaceous shrubs in Western North America. Subjects include: (1) distribution, taxonomy, and habitat classification; (2) growth performance, phenology, and physiology; (3) successional relationships; (4) management strategies; (5) animal relationships; (6) soil-plant nutrient relationships; and (7) fire relationships.

KEYWORDS: rosaceous shrubs, *Purshia*, *Cowania*, *Fallugia*, Rosaceae, distribution, taxonomy, habitat classification, growth, phenology, physiology, succession (plants), management, animals, soil nutrients, nitrogen fixation, fire

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Aspen Succession in the Intermountain West: A Deterministic Model

Dale L. Bartos, Frederick R. Ward,
and George S. Innis

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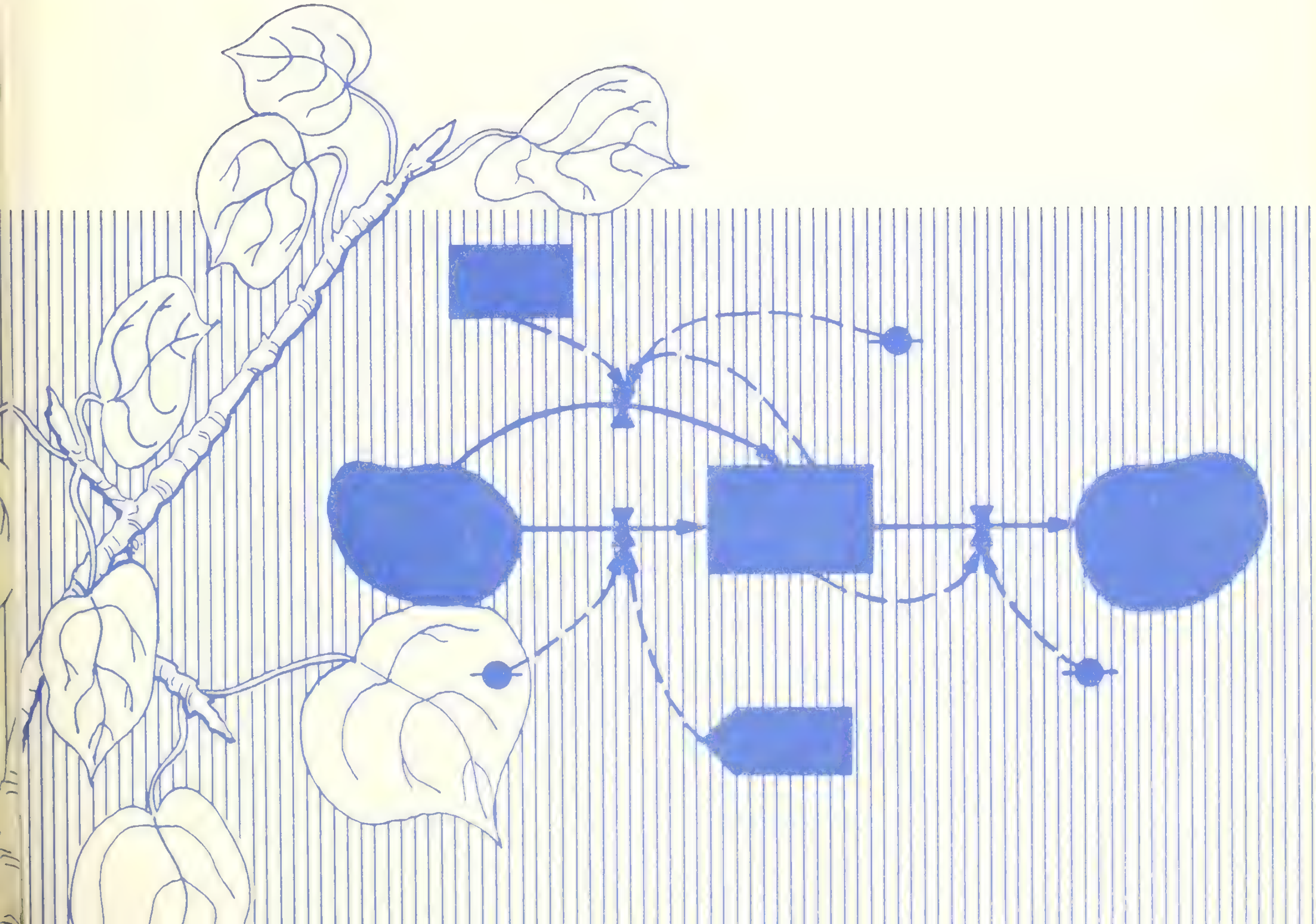

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RESEARCH SUMMARY

A deterministic model of succession in aspen forests was developed using existing data and intuition. The degree of uncertainty, which was determined by allowing the parameter values to vary at random within limits, was larger than desired. Analysis of model sensitivity to changes in parameter values was made and the results presented. These results have indicated areas of needed research. The model responds realistically to various management techniques and could be an aid to resource managers in their decision making process.

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Aspen Succession in the Intermountain West: A Deterministic Model

Dale L. Bartos, Frederick R. Ward, and George S. Innis

INTRODUCTION

The aspen (*Populus tremuloides* Michx.) ecosystem is prevalent in the mountainous West (Little 1971). This system produces multiple resources including: water, wildlife habitat, recreational sites, summer grazing for domestic livestock, wood fiber, and esthetics.

To manage the aspen system and its resources intelligently, we must understand the natural forces acting upon and within the ecosystem. When we understand the dynamics of the vegetation, we can make valid judgments concerning management of these lands for the resources mentioned above. The process of succession also needs to be better understood so that the successional position of a particular stand can be identified and the stand managed accordingly.

Much of successional theory has been developed for mesic, temperate forests. Many of these theories have been incorporated into simulation models tracking the dynamics of the forested system following disturbance. Shugart and West (1980) review much of this literature and Trimble and Shriner (1981) inventory many of the published and unpublished models.

More than 200 years is required for conifers to invade and dominate aspen forests. Long-term intensive studies are not feasible to answer pressing and current management problems. Using existing data and intuition, Bartos (1973, 1978) developed a simulation model as an aid to understanding the dynamics of the aspen system. We have revised this model by reducing the number of parameters, while still retaining the structure and behavior of the model.

The model presented here considers a site as a homogeneous unit on which plants (trees, shrubs, and herbs) are growing. Because the model addresses average conditions on an area, it is more like the model of Noble and Slatyer (1977) than the family of models produced by Botkin, his associates and followers (Botkin 1977; Botkin and others 1972a, b; Shugart and West 1977). Our model is concerned with the alternative fates of an aspen/conifer site following a major disturbance (fire or clearcut). These alternatives, described by Mueggler (1976), include succession to conifers, remaining in aspen, or succession to meadow, again suggesting the Noble and Slatyer model. To date, our model treats only the first alternative. Implementation of other alternatives is straightforward, depending only on the identification of mechanisms responsible for the alternate pathways.

Our model is most like that of Sperger (1980), although the latter model is very elaborate. Sperger includes many more size classes in his model so that he can predict the size class distribution of the forest at any age. We deal with aspen and conifer reproduction in three different size classes, and beyond that we consider only biomass. Therefore, our model requires less data than Sperger's model for a particular run.

With all the published successional models, why do we presume to build another? First, much of the utility in a modeling exercise derives from the design and construction of the model (Innis 1972; Odum 1981). This utility is denied one who attempts to use another's model. Because models are specific to their applications, model building begins with statements of the objectives. Each of the published models has different objectives and, consequently, different structure. We must appreciate this dependence on objectives when evaluating a model.

In addition to the "standard" run showing succession in the aspen forest following a disturbance, this paper includes responses of the model to common management techniques. As an aid to interpretation of model results, an indication of the distribution of the model results as a function of uncertainty of the parameter values used is presented. The model is very sensitive to changes in some parameter values, and this sensitivity is discussed.

Model Objective

Our objective was to develop a streamlined simulation model that would predict the dynamic nature of vegetation components within the aspen system and how these components change during the successional process. This model should apply to most aspen lands in the western United States and should aid natural resource managers in their decisionmaking process. In addition, a good responsive model would aid in studying the aspen system. Such a model would provide an excellent basis on which to develop a problem analysis for future research. Individual studies could be conducted to more accurately estimate the most sensitive parameters.

Several terms in this statement of objectives require further elaboration: 1. "Dynamic" implies changes over time in the various vegetation components of the system. 2. "Vegetation component" refers to only the aboveground biomass for wood (aspen and conifers) and herbage (shrub and herb species). 3. "Successional process" is the dynamics of a vegetation unit as it progresses towards a community that is in a steady state (climax) relationship with the environment. We are concerned only with secondary succession—where the soil may remain at a fairly advanced stage of development while the plant community is set back to an earlier stage because of a disturbance.

4. "General model" implies flexibility to apply the model to different sites which have similar environmental conditions. The model needs to assimilate disconnected bits of information and predict within reason the results of management practices.

While this objective statement sets the general tone of the modeling effort, a more explicit set of issues must be addressed:

1. Does the modeled successional pattern fit the intuition of experts?
2. Does the model respond reasonably to management actions?
3. Without major influences from conifers and herbs, is an aspen community able to stabilize for long periods of time?
4. What are the sensitivities of these predictions to parameter estimates, site condition assignments, initial conditions, and functional forms of flows?
5. What additional research is needed to make this model a more accurate simulation of the consequences of succession?

Assumptions

Several assumptions were made to facilitate initial model development and subsequent updates. The initial assumptions are: 1. The system stressed will have conifers on or near it to provide a seed source when the site is disturbed. 2. Aspen are present; therefore, a root source exists to provide a flush of aspen suckers when the site is disturbed. 3. The damaged site will be small enough to be homogeneous with respect to soil characteristics and abiotic factors. 4. Disturbance will be by burning; some root crowns of perennial herbs will not be killed and total herb production will be temporarily stimulated when the site is disturbed. (The community could quite conceivably be stressed by cutting the overstory trees and similar responses might be observed.)

MODEL STRUCTURE

The major components of interest in this model are aspen, conifers, shrubs, and herbs. These regenerate, grow, and die at rates affected by the various components (fig. 1). Soil and climate are not explicitly treated in the model but are reflected in site-specific parameters such as growth rate, regeneration rate, and maximum biomass of the various compartments. The mathematical model is a set of simultaneous difference equations. The model was coded in FORTRAN V and runs on a variety of computers. (A complete listing of the computer program is presented in appendix A.) The model is deterministic, not stochastic, in nature. Parameter values used (see appendix C) reflect long-term averages adjusted for the step size, which we set at 1 year.

Primary concern is aboveground biomass (kg/ha) of the four major state variables. Aspen suckers and conifer seedlings, however, are treated in three size categories on the basis of density because growth, mortality, and interactions with other compartments are very different for the suckers and seedlings than for mature individuals and should be handled in a different fashion.

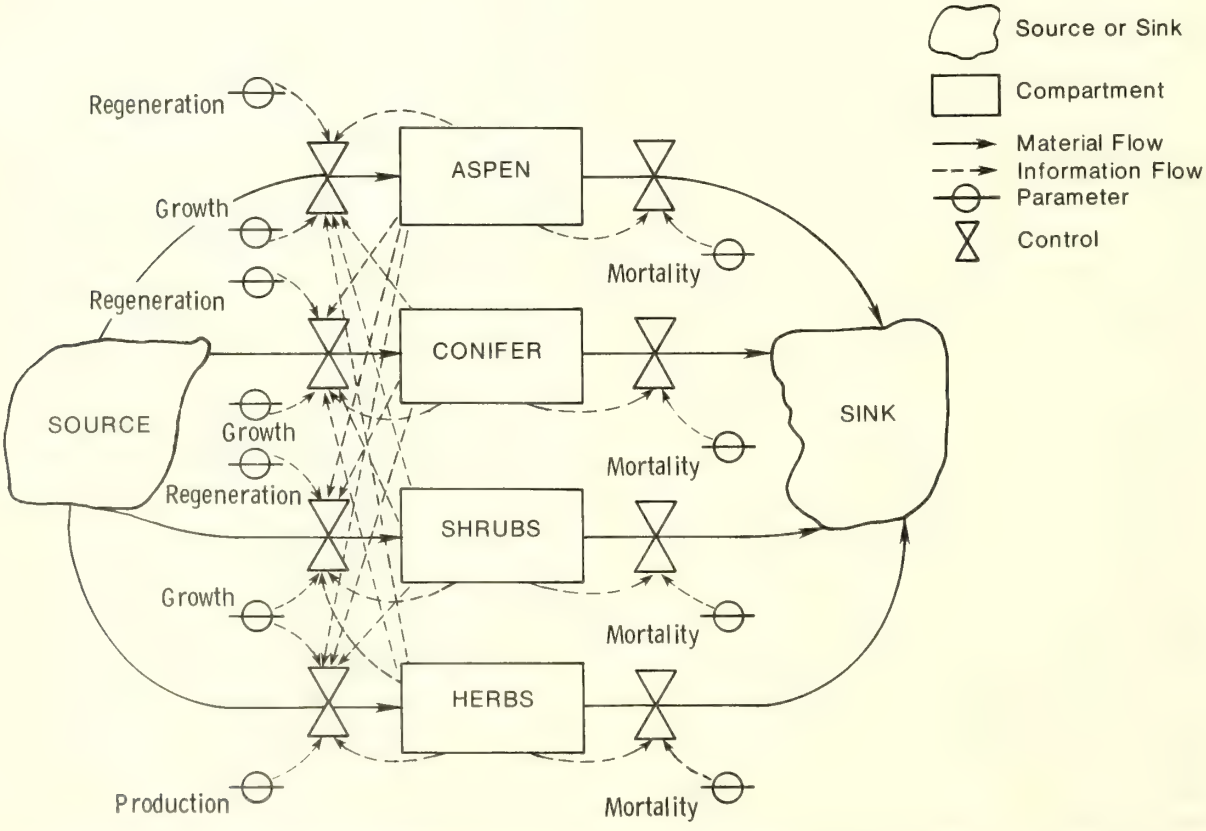


Figure 1.—Summary flow diagram of major compartments in the ASPEN model.

The aspen reproduction categories are: ASP1, aspen suckers less than 0.5 meters tall; ASP2, suckers between 0.5 and 2 meters tall; and ASP3, suckers over 2 meters tall but less than 5 cm d.b.h. All aspen reproduction is considered to be vegetative. For conifers the three categories of seedlings are CON1, CON2, and CON3, defined according to the same size structure as the aspen suckers. CON1 seedlings are considered to be established (to have persisted on the site for at least 3 years) to avoid dividing them into several subgroups. Time for passage through these subgroups is accounted for by a time delay. Thus, no regeneration into CON1 is allowed for a few years (3 to 10 depending on the site) after the initial disturbance. The numbers of individuals graduating from ASP3 and CON3 are converted to biomass using average weights of 5 cm d.b.h. aspen and conifer and constitute the regeneration flows from the source to the biomass compartments of aspen and conifer. These two major compartments contain the biomass only of individuals larger than 5 cm d.b.h.

In the case of shrubs, mature plants were not considered sufficiently different from the young ones to warrant separate treatments; so the shrub compartment contains individuals of all sizes.

The herb compartment was subdivided into annuals and perennials. Because only the aboveground biomass is considered, these compartments are totally depleted each year. Production was not separated into reproduction and growth.

Flows representing regeneration, growth, production, or graduation are controlled by the product of a maximum rate with two or more inhibiting functions having values which range over the interval from 0 to 1. For example, the graduation of conifer seedlings from CON3 to CON is given by FLOW27 = CON3 * P(101) * Z1 * Z2 where P(101) gives the maximum graduation rate allowed, Z1 = 1 − 0.5 * PASP gives the restriction of the aspen, and Z2 = 1 − 0.7 * PCON gives the restriction of the conifers. The maximum rates are given by parameters reflecting site characteristics, and the functions represent restrictions imposed on that flow by various compartments. The independent variable for each restricting function is taken to be the ratio of the present value to the maximum possible value of the inhibiting compartments, rendering these functions independent of site.

With one exception, the influence of aspen on conifer reproduction which will be discussed later, these inhibiting functions are nonincreasing. When the inhibiting compartment has a value of zero, the ratio of present to maximum value is zero and the inhibiting function has a value of 1 (no restriction). As the value of the inhibiting compartment increases, the ratio of that value to the maximum increases and the value of the inhibiting function decreases below 1 so that there is a more stringent restriction.

The inhibiting functions were suggested in graphic form by members of the Aspen Ecosystem Project (INT-RWU-1751) at the Intermountain Station's Forestry Sciences Laboratory in Logan, Utah. We then fitted these curves with functions and they were approved by consensus of the project scientists as exhibiting appropriate behavior.

All compartments other than sources and sinks were considered to have potential influence on a flow. If this influence was considered quite minor, as in the case of herbage on growth of large conifers, it was omitted. In cases where intensive investigation has yielded more detailed knowledge, the influences were considered separately, but where less was known the influences were pooled. For instance, the three aspen sucker compartments separately affect the regeneration of ASP1, but the three conifer seedling compartments are pooled into one compartment, which has a single restriction on ASP1 regeneration. The detailed discussion of the model structure includes graphs of the functions restricting the flows into the various compartments. Each graph is accompanied by its equation, and the flow equations into and out of each compartment are given.

Each mortality flow in the model is a fixed percentage of the value of the compartment from which the flow originates; for example, the mortality of conifers is given by the equation FLOW6 = CON * P(105). In the biomass compartments "mortality" is interpreted to include the loss of portions of a plant as well as of entire plants. These mortality rates are site-specific parameters. During the model building process there was much discussion concerning the mechanisms which limit a compartment to some maximum value. In the absence of firm knowledge as to whether (1) the mortality rate increases to surpass the growth rate, (2) the growth rate drops to the mortality rate, or (3) the growth rate decreases over time as the mortality rate increases, it was decided to hold mortality constant and decrease growth from some maximum value by means of the various restrictions. In the aspen compartment, for example, maximum growth rate is set at 8 percent per annum and mortality rate is set at 3 percent per annum. This allows for a net growth of 8 percent − 3 percent = 5 percent per annum in the extreme case that little aspen and no conifer is present to curtail the growth rate. A heavy conifer stand, however, would restrict aspen growth rate to nearly zero, yielding a net growth of 0 percent − 3 percent = −3 percent per annum, the mortality rate.

Large-scale losses, such as those induced by disease or insect infestation, are outside the purview of the model. One could treat such high mortality, however, by stopping the simulation and restarting with new initial values that reflect the appropriate loss.

At the beginning of a simulation run the computer assigns and prints the maximum possible values of various compartments (code 11100–13700). The maximum value of a compartment represents the level that compartment could contain in the absence of any competition from other compartments. Input parameters give the maximum values of mature aspen, mature conifer, shrubs, annuals, perennials, the three aspen sucker classes, the three conifer seedling categories, the pooled biomass equivalent of the conifer seedlings, the pooled biomass equivalent of the aspen suckers, and the combined biomass possible for shrubs and aspen suckers. Maximum herbage is the sum of the maxima of the annual and perennial compartments.

Some initial values are assigned through parameters and others are computed from those values assigned (code 14400–18100). Those assigned are for aspen and its three sucker classes, conifer and its three seedling classes, annuals, perennials, shrubs, and number of mature conifers. Those computed include total herbs and other combinations of compartments with assigned initial values.

Computation of flows requires that ratios of present value to maximum possible value for numerous compartments be computed at each time step (code 24700–27700). The FORTRAN name for such a ratio is the FORTRAN name for the compartment with a prefix of P; for instance, PASP stands for the ratio of aspen present to aspen possible. Should such a ratio exceed 1, the value of the corresponding inhibitor function becomes negative, which causes anomalous behavior; so a check is made to reset the ratio to 1 in case its computed value exceeds 1.

Regeneration and mortality of ASP1 (code 28000–29600) are diagramed in figure 2. ASP1 mortality is given by FLOW15 = ASP1 * P(41), where P(41) is the site-specific mortality rate. ASP1 regeneration is given by FLOW14 = P(40) * Z1 * Z2 * Z3 * Z4 * Z5 * Z6 * Z7 where P(40) is the site specific rate and the factors Z1, Z2, Z3, Z4, Z5, Z6, and Z7 are the restrictions contributed by ASP, CON, SHU, ASP1, ASP2, ASP3, and CONN respectively (fig. 3). Note that as the ratio of present to maximum possible biomass goes from 0 to 1, the corresponding restriction increases from 1 (no restriction) to a fraction nearer 0.

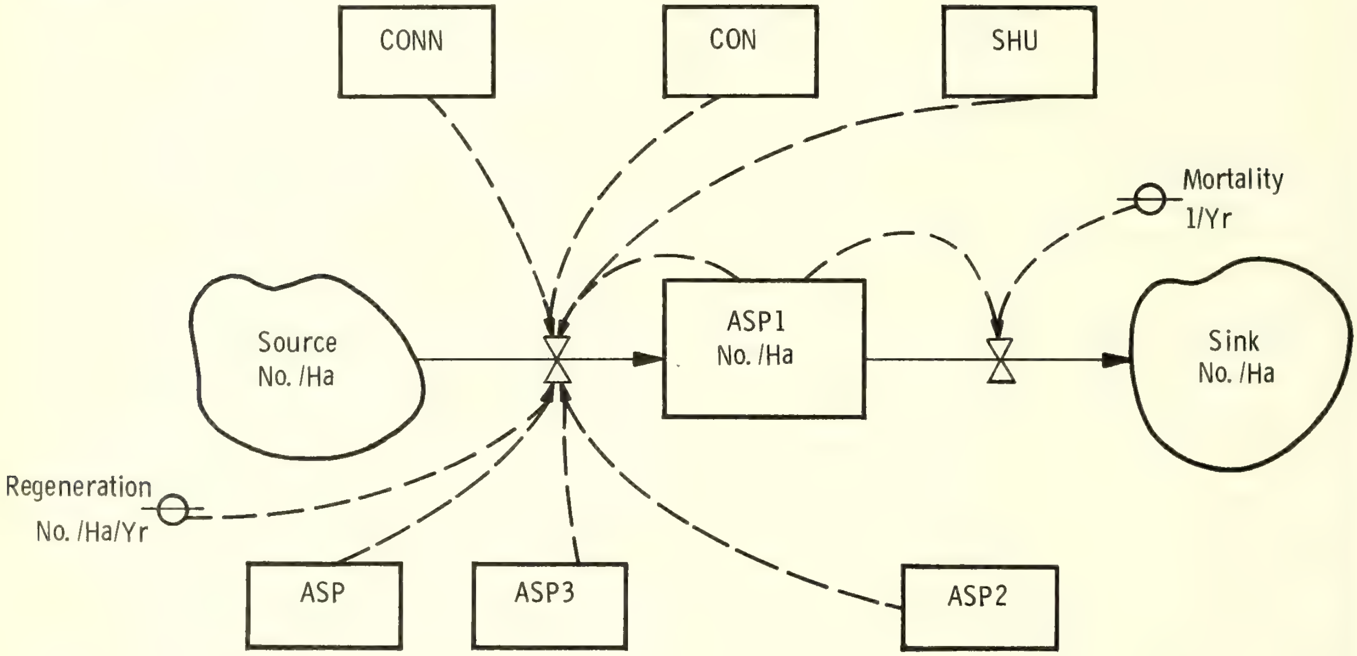
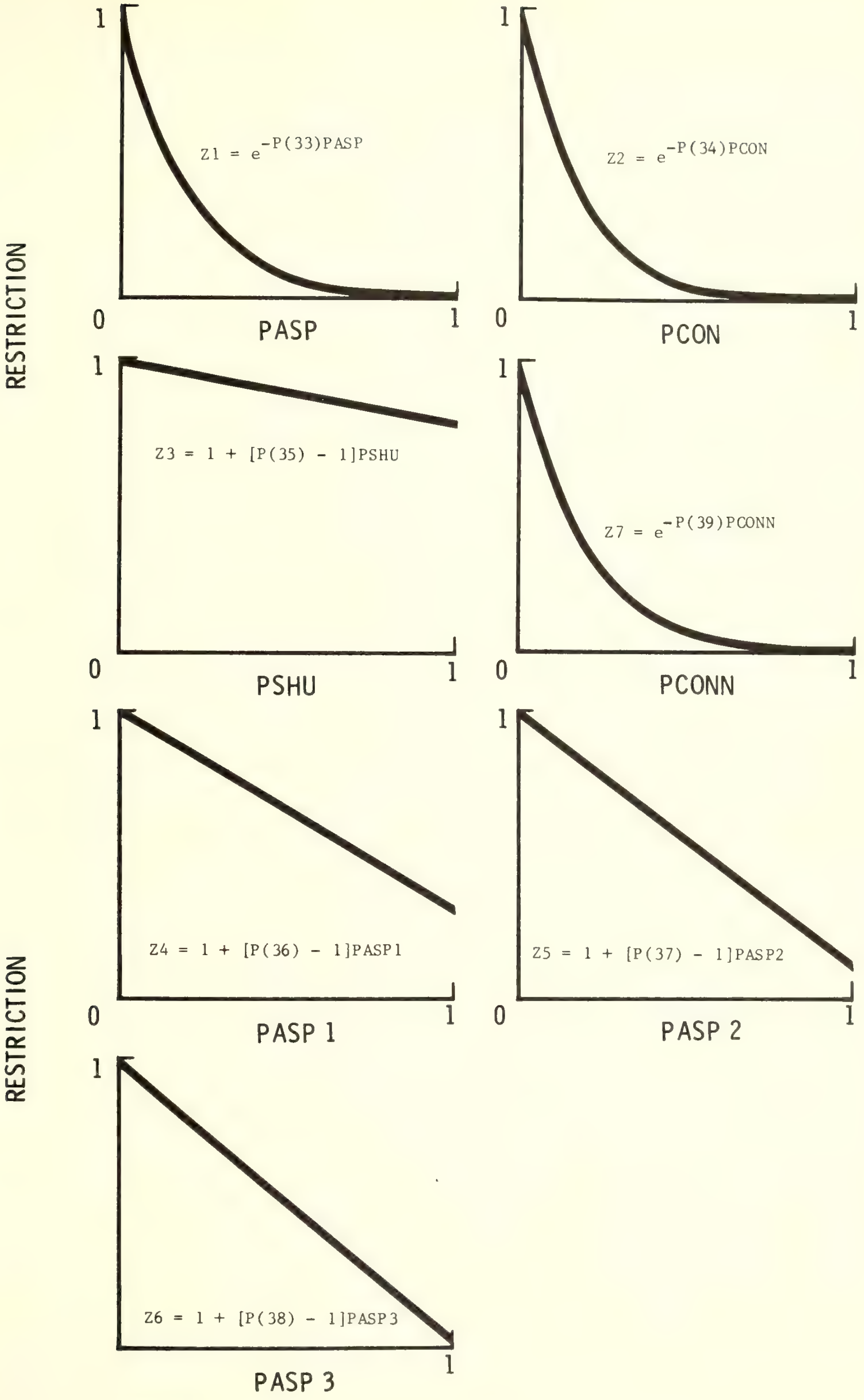


Figure 2.—Flow diagram depicting regeneration and mortality of ASP1.



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FLOW 14 = P(40) * Z1 * Z2 * Z3 * Z4 * Z5 * Z6 * Z7
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Figure 3.—Functions that inhibit the regeneration of ASP1.

Each year some fraction of the ASP1 is allowed to graduate to ASP2 and a fixed proportion of the ASP2 die (code 29700–31300). The flows are diagramed (fig. 4) and the nature of the restrictions is shown in figure 5. The ASP1 restriction is considered negligible in this case, but the herbs are not. While the herbs may not restrict suckering of aspen, they do compete with the young suckers for light.

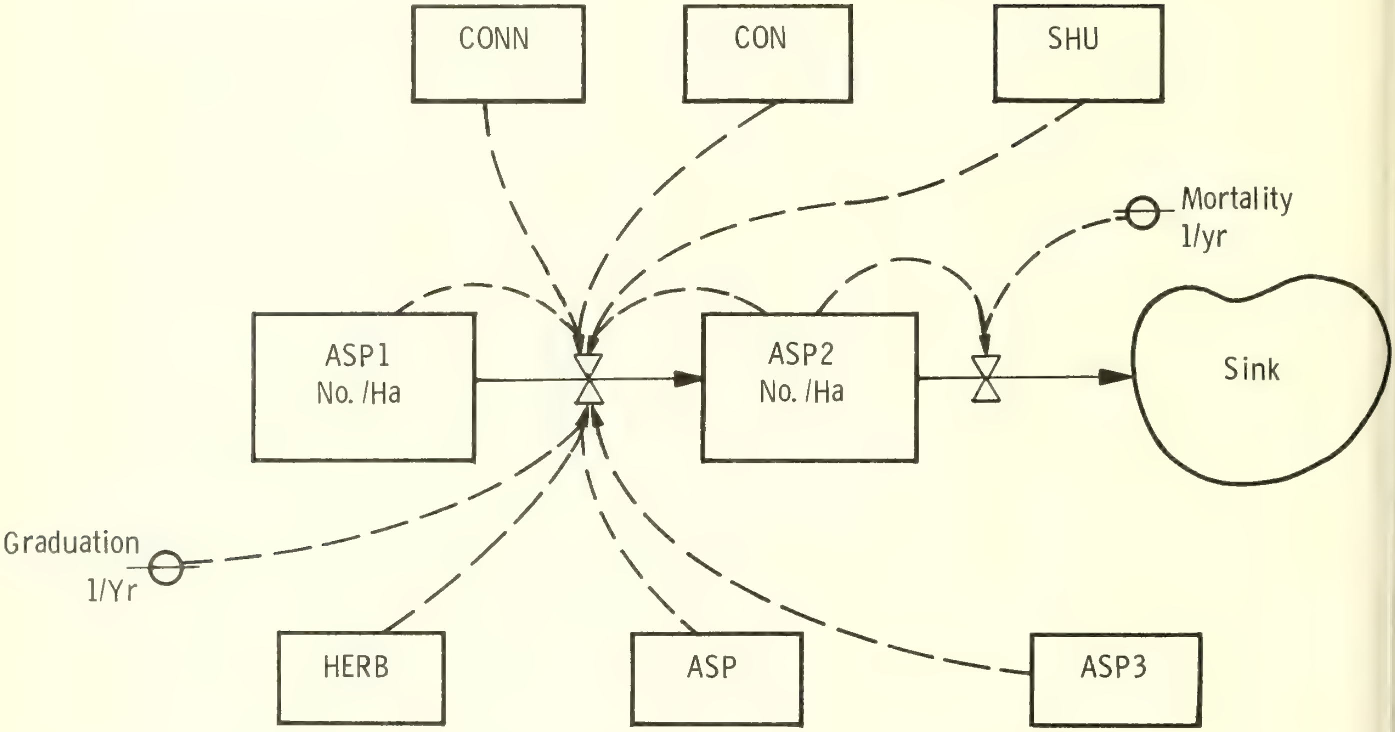
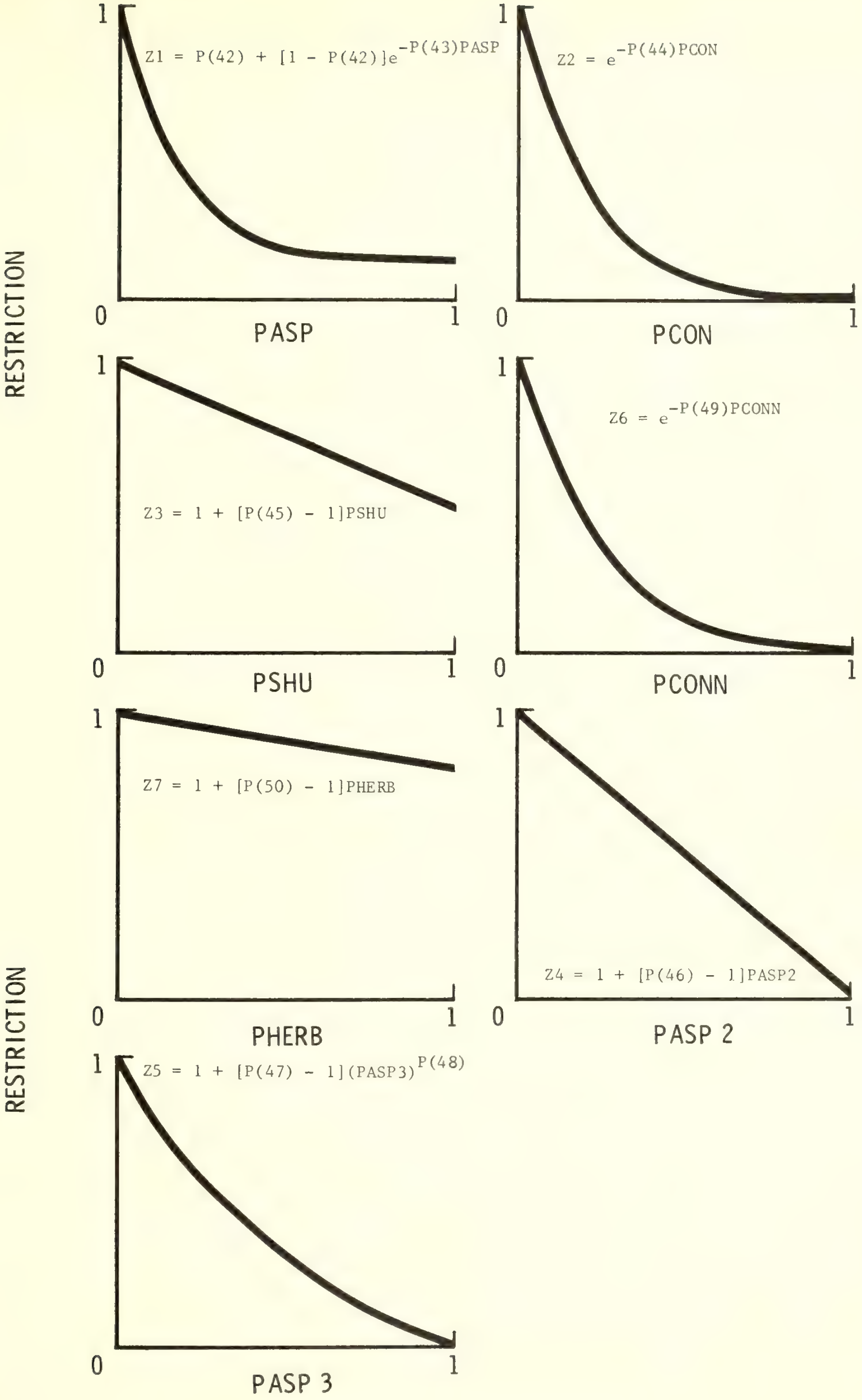


Figure 4.—Flow diagram depicting graduation from ASP1 to ASP2 and mortality from ASP2.



FLOW 16 = ASP1 * P(51) * Z1 * Z2 * Z3 * Z4 * Z5 * Z6 * Z7

Figure 5.—Functions that inhibit the graduation of ASP1.

Graduation from ASP2 to ASP3 and mortality of ASP3 (code 31400–32800) are shown in figure 6. At this point restrictions due to herbs and ASP2 are considered negligible. Inhibitions from the other compartments are graphed in figure 7.

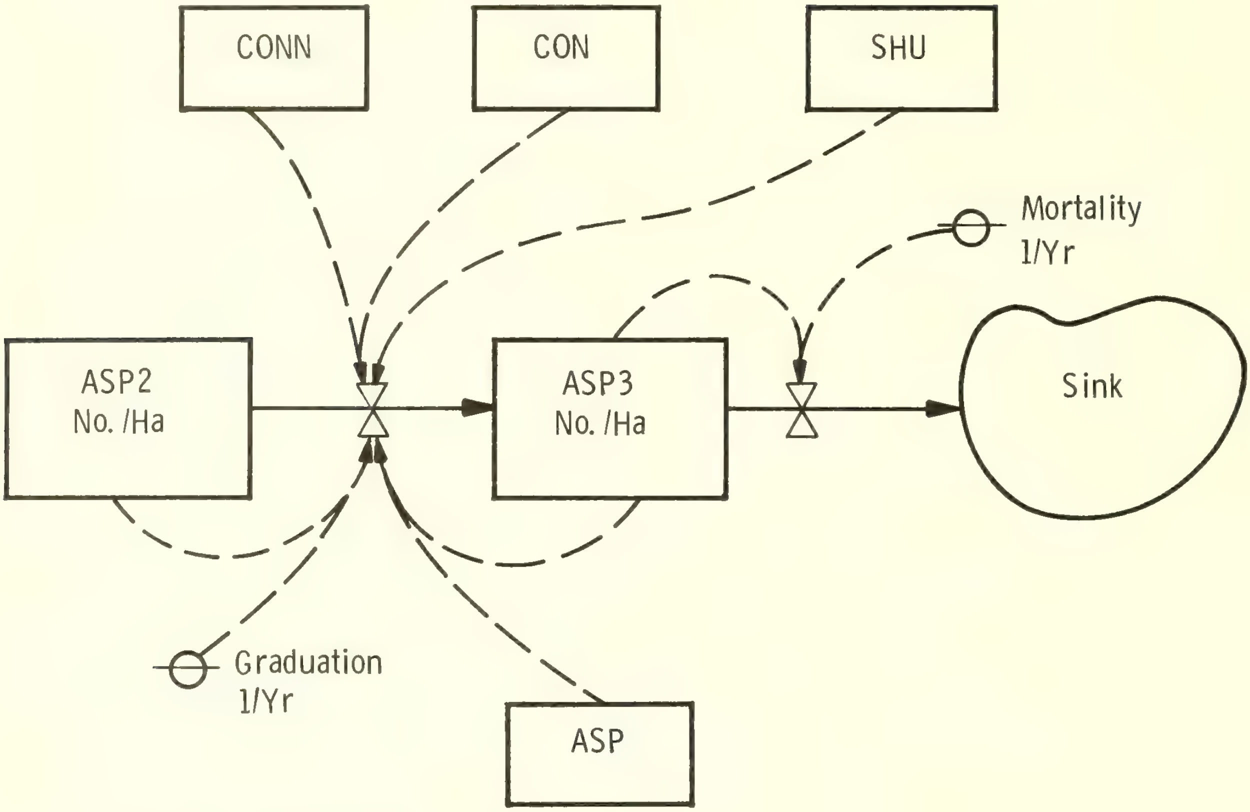
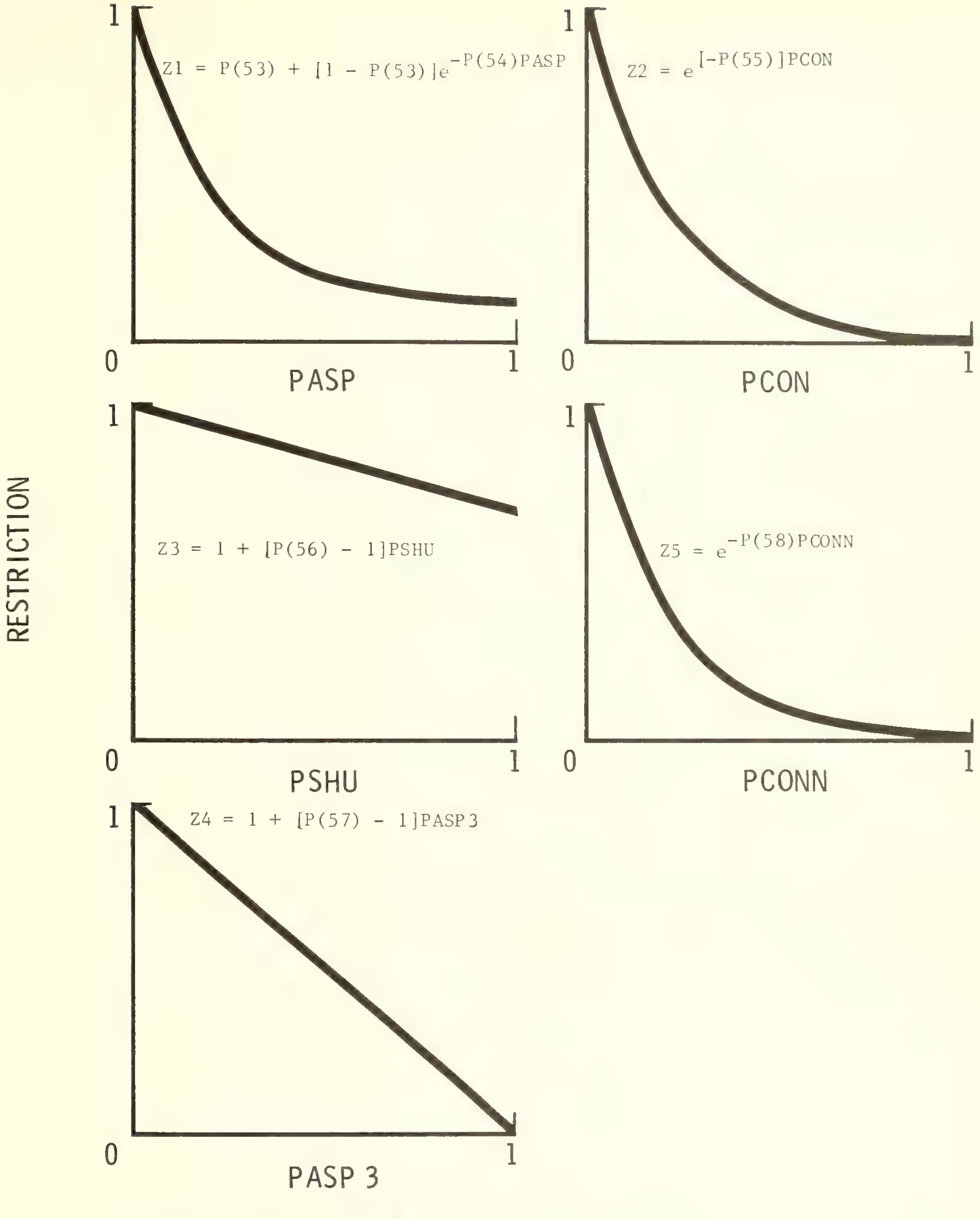


Figure 6.—Flow diagram depicting graduation from ASP2 to ASP3 and mortality from ASP3.



FLOW 18 = ASP2 * P(59) * Z1 * Z2 * Z3 * Z4 * Z5

Figure 7.—Functions that inhibit the graduation of ASP2.

To ensure a conservative system, graduation from ASP3 (code 32900–33600) is shown in figure 8 as going to the sink. The sum of the values in the three aspen sucker compartments and their source and sink should remain constant. Only the conifer, aspen, and shrub compartments have identifiable restrictions on the flow (fig. 9).

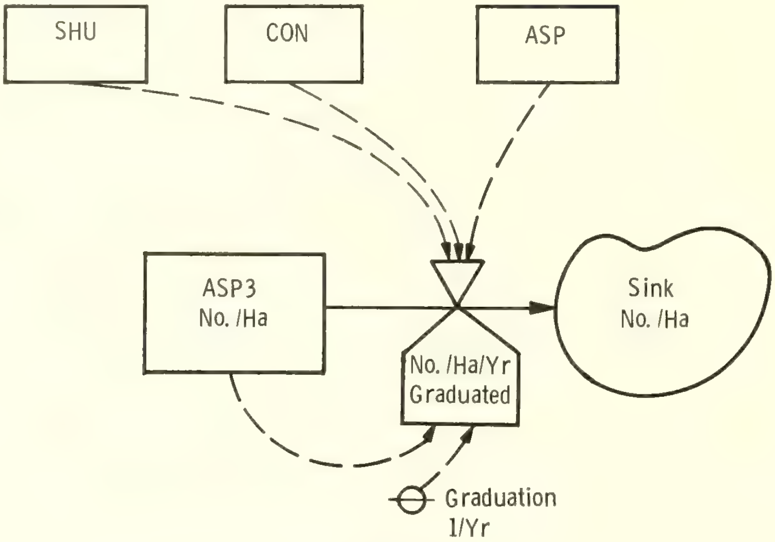
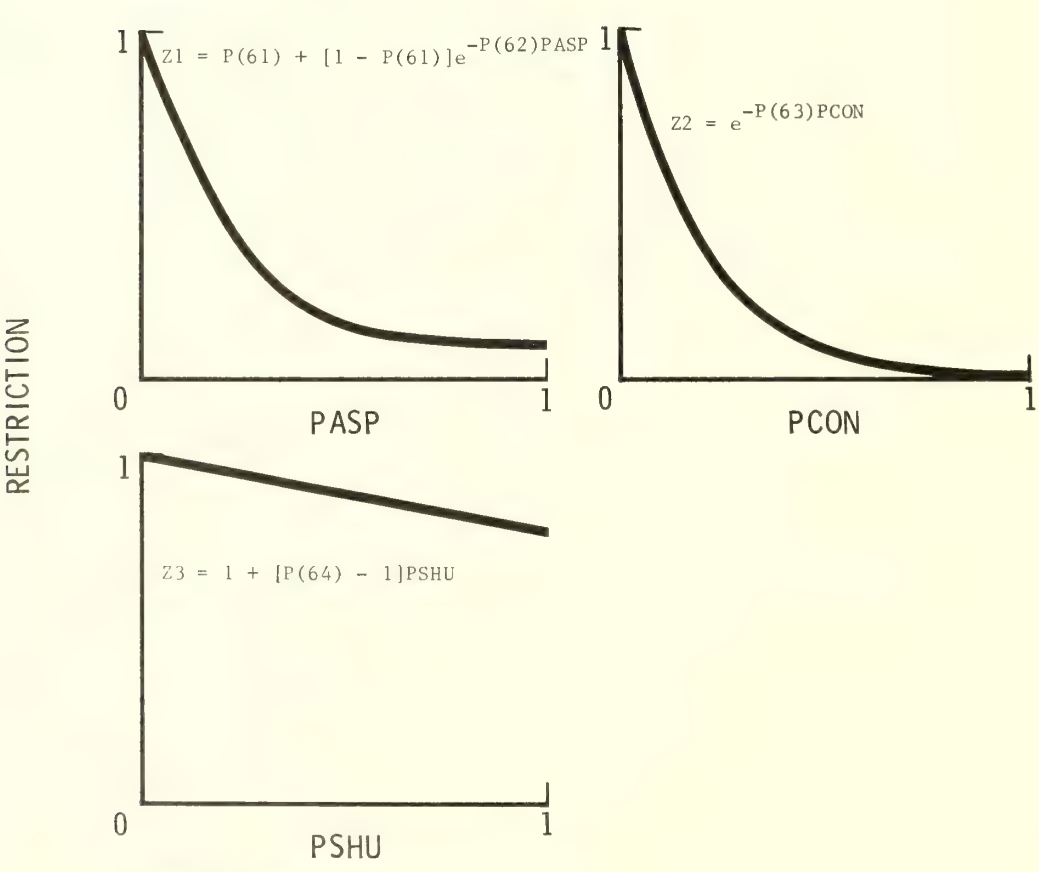


Figure 8.—Flow diagram depicting graduation of ASP3.



FLOW 20 = ASP3 * P(65) * Z1 * Z2 * Z3

Figure 9.—Functions that inhibit the graduation of ASP3.

There are two flows from the source to ASP in figure 10. The lower flow is simply the conversion of ASP3 graduation from numbers to biomass (code 33700–34100). The upper flow from the source and the flow to the sink represent aspen growth and mortality (code 34200–35300). The restrictions of the aspen and conifer on aspen growth are shown in figure 11. The restriction due to aspen itself is such that the product of the restriction with the growth rate would equal the mortality rate slightly before maximum biomass is reached. This produces a net mortality as aspen biomass approaches maximum so that aspen biomass will not continue to increase past maximum due to graduation from ASP3.

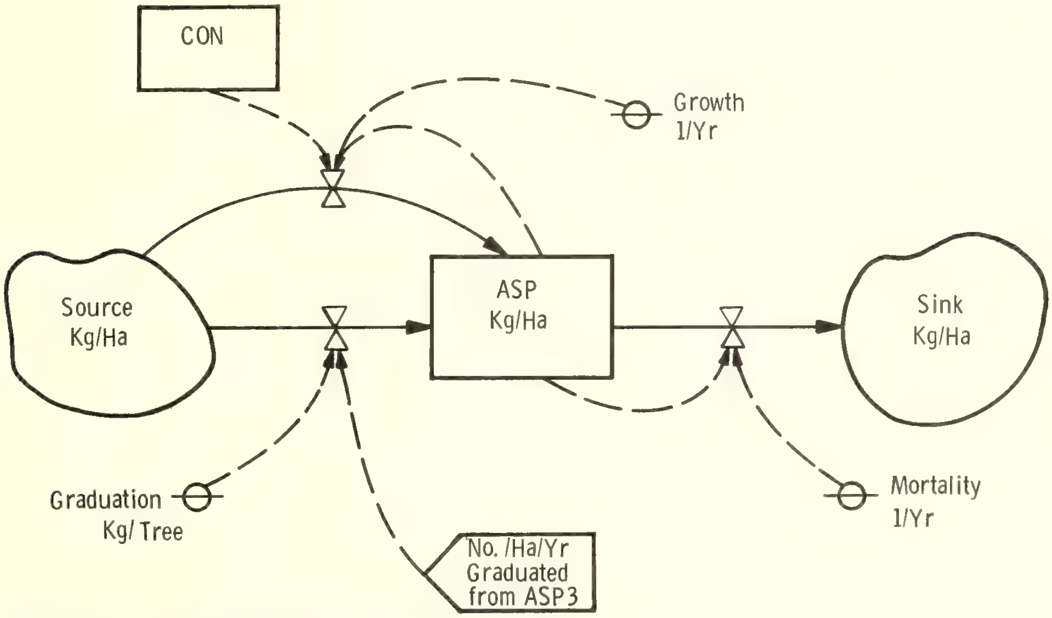


Figure 10.—Flow diagram depicting regeneration, growth, and mortality of aspen (ASP).

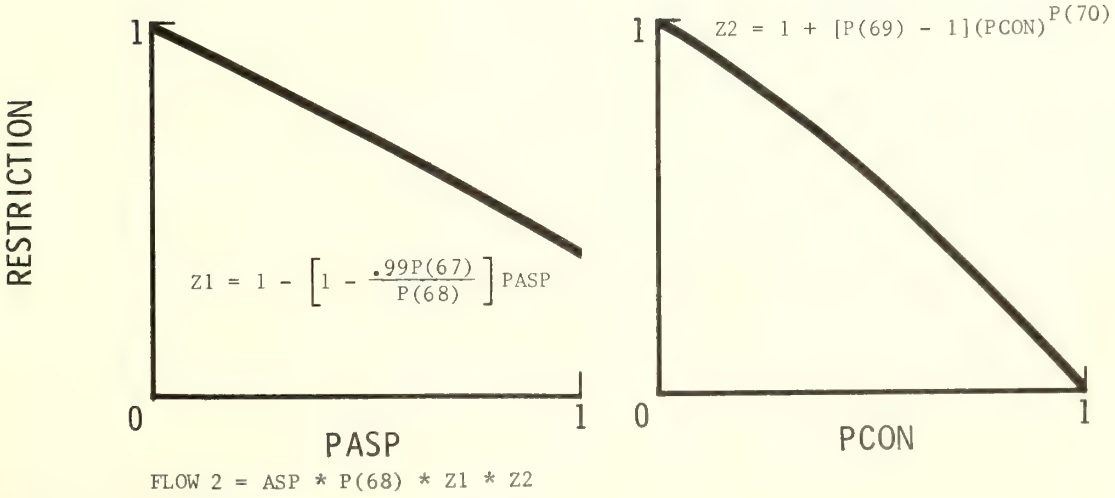


Figure 11.—Functions that inhibit the growth of aspen.

Regeneration and mortality of CON1 (code 35400–37600) are diagramed in figure 12. As in the case of ASP1, the relative mortality and maximum rate of regeneration are site specific. All compartments except CON1 affect the regeneration rate, though annuals and perennials are pooled as a single effect in HERB and the aspen suckers are converted to biomass and pooled with shrubs as SHUH (fig. 13). The restriction of aspen on CON1 regeneration is the only inhibiting function which is not strictly decreasing. This deviation from the norm was designed to account for a "nurse" effect of aspen on conifer regeneration. Controversy revolves around this point, however, with some arguing that there is no positive effect from aspen on the conifer seedlings.

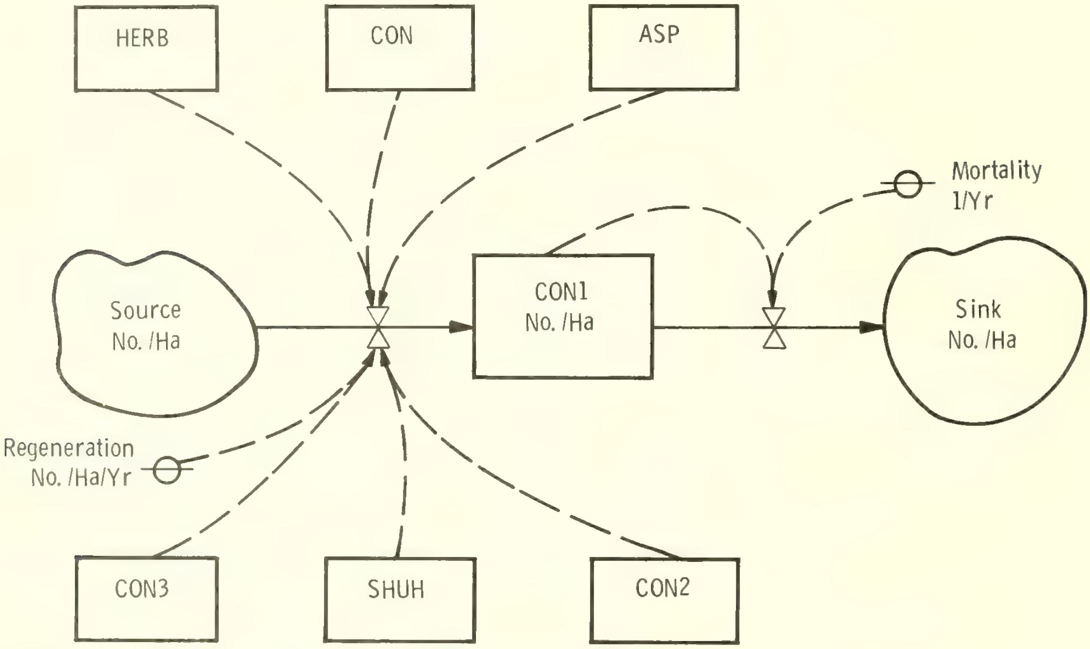
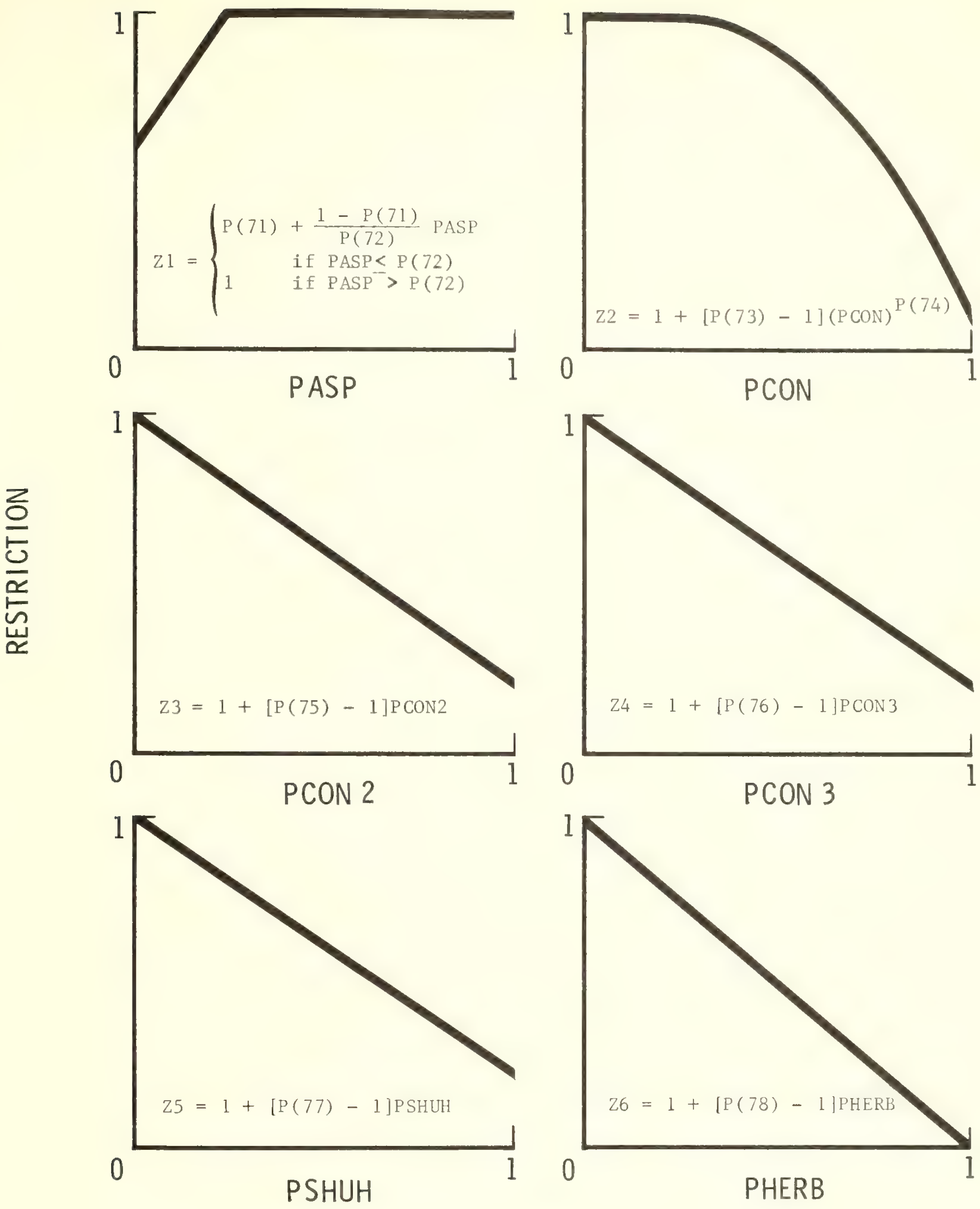


Figure 12.—Flow diagram depicting regeneration and mortality of CON1.



FLOW 21 = P(79) * Z1 * Z2 * Z3 * Z4 * Z5 * Z6

Figure 13.—Functions that inhibit the regeneration of CON1.

Graduation of CON1 to CON2 and mortality of CON2 (code 37500–39000) are diagramed in figure 14. The graduation is affected by the same compartments as is regeneration (fig. 15).

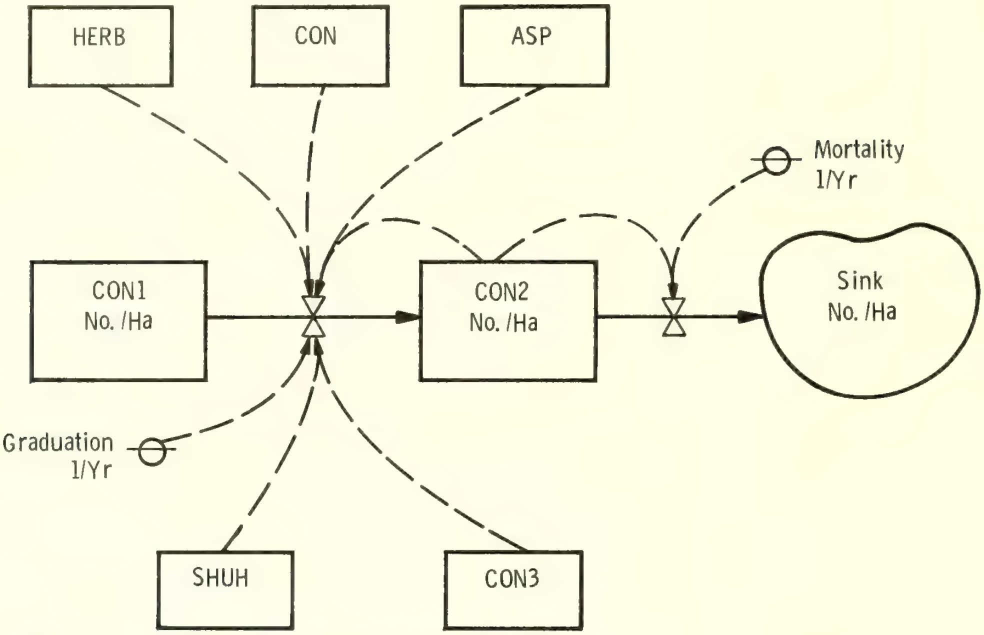
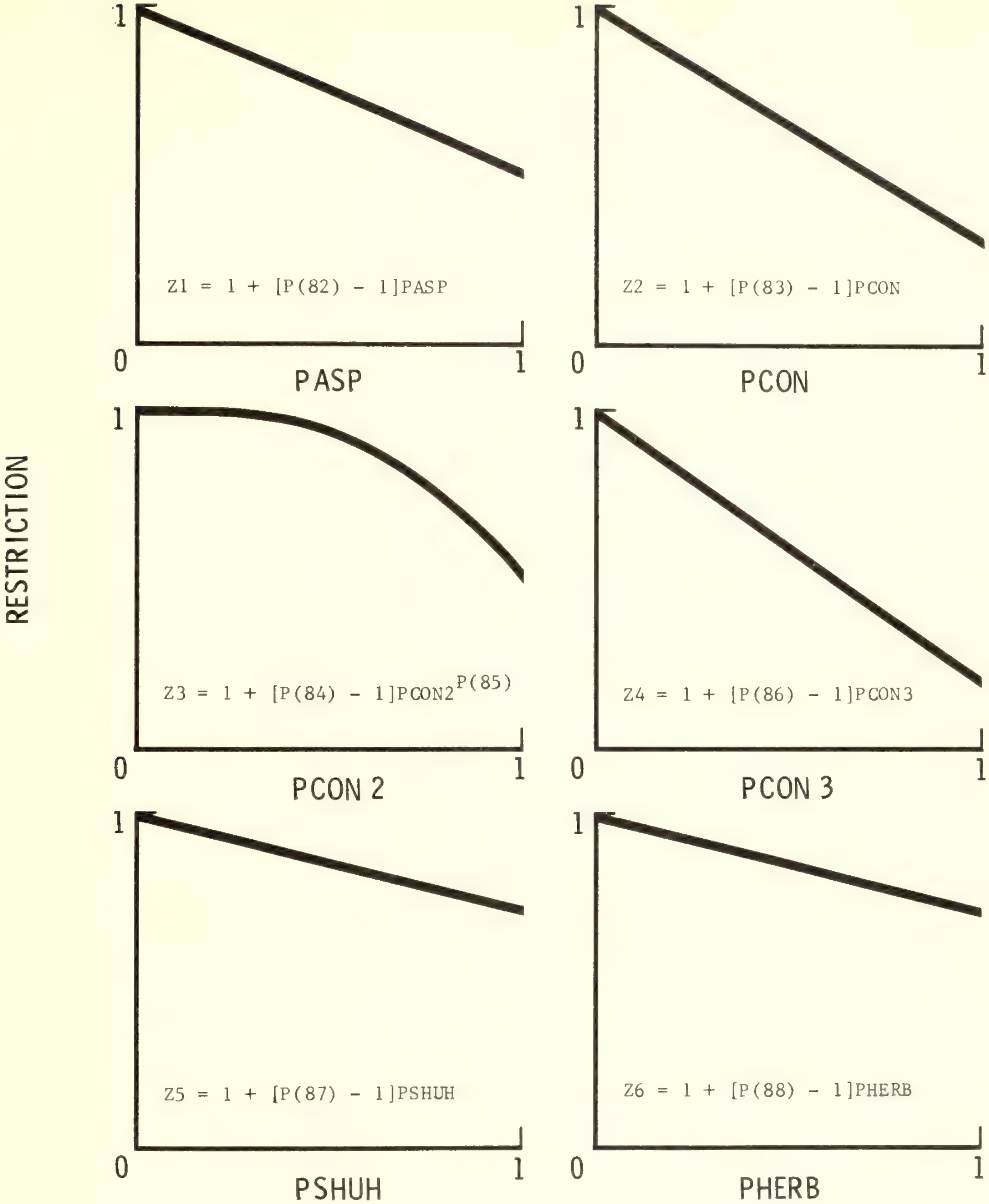


Figure 14.—Flow diagram depicting graduation of CON1 to CON2 and mortality of CON2.



FLOW 23 = CON1 * P(89) * Z1 * Z2 * Z3 * Z4 * Z5 * Z6

Figure 15.—Functions that inhibit the graduation of CON1.

The diagram of CON2 graduation and CON3 mortality (code 39100–40400) is in figure 16. In the graduation of CON2 the herbs, shrubs, and aspen suckers are no longer considered significant factors. The remaining inhibitions are shown in figure 17.

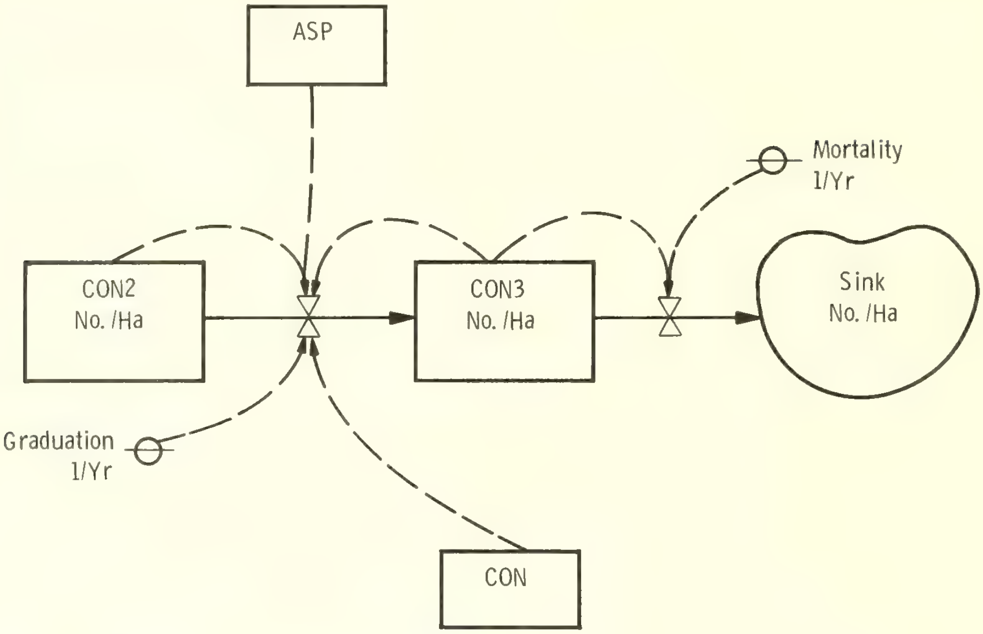
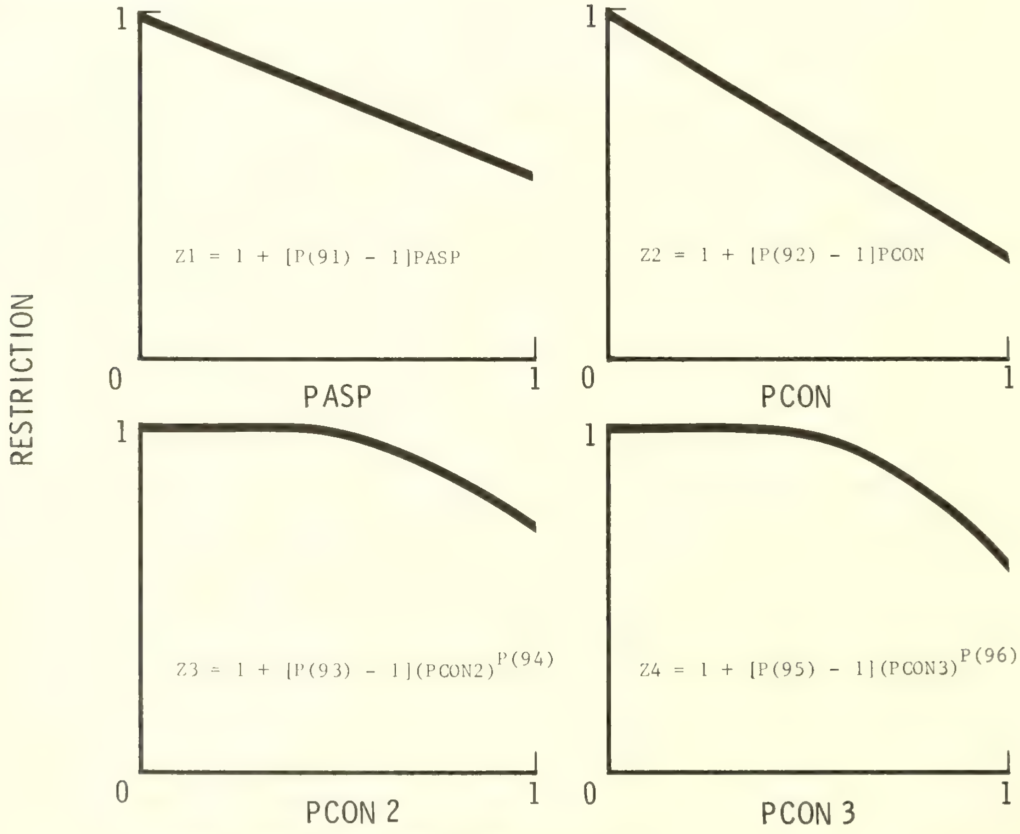


Figure 16.—Flow diagram depicting graduation of CON2 to CON3 and mortality of CON3.



FLOW 25 = CON2 * P(97) * Z1 * Z2 * Z3 * Z4

Figure 17.—Functions that inhibit the graduation of CON2.

Like ASP3, the CON3 seedlings graduate to a numbers sink (code 40500–41100) (fig. 18) with restrictions (fig. 19). The sum of the values in the source, the sink, and the three seedling compartments should remain constant over the years. Because the mortality applied to the conifer numbers (code 42400–42800) is the same fraction as that applied to the conifer biomass, all the loss of smaller limbs shows up as loss of tree numbers, so that the numbers estimate grows continually smaller and average tree size estimates are too large.

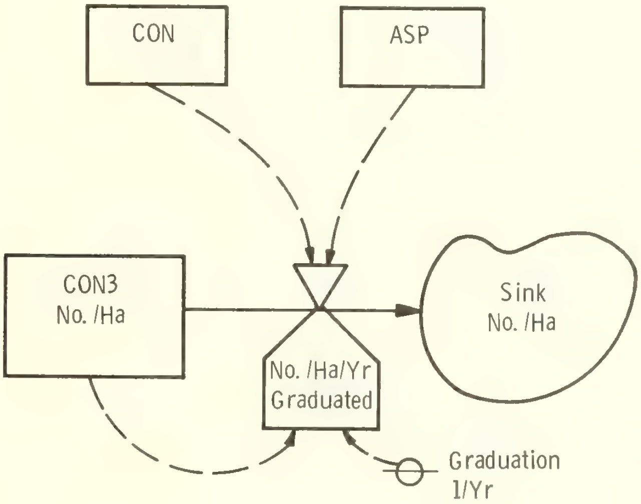
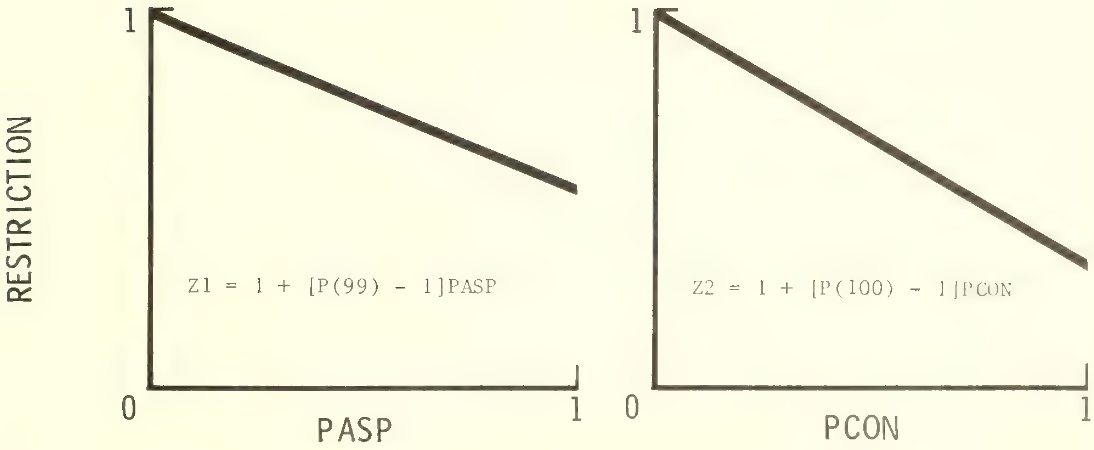


Figure 18.—Flow diagram depicting graduation of CON3.



FLOW 27 = CON3 * P(101) * Z1 * Z2

Figure 19.—Functions that inhibit the graduation of CON3.

The two flows into the conifer compartment from the source and the single flow out to the sink are shown in figure 20. The lower flow from the source is the conversion of CON3 graduation to biomass (code 41200–41600). The outflow is mortality (code 42900–43300), and the upper flow is in conifer growth (code 41700–42300), which is affected only by aspen and the conifer itself (fig. 21). The manner in which aspen affects conifer growth is quite critical and parameter 103, which gives the maximum restriction of aspen on conifer growth, is probably the one to which the model is most sensitive. Changing this curve can drastically alter the response of the system. The inhibition of CON on CON growth is designed, as in the case with aspen, to prevent an increase beyond maximum biomass in the CON compartment due to influx from CON3 graduation.

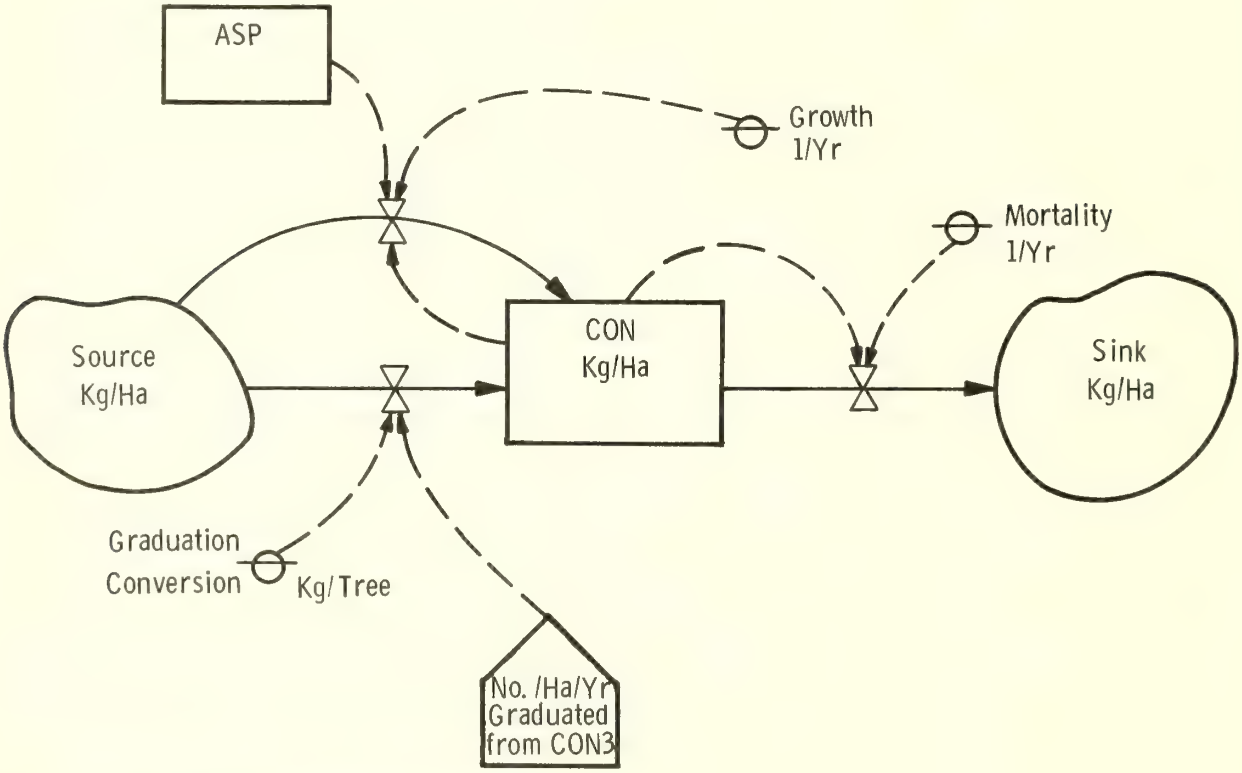
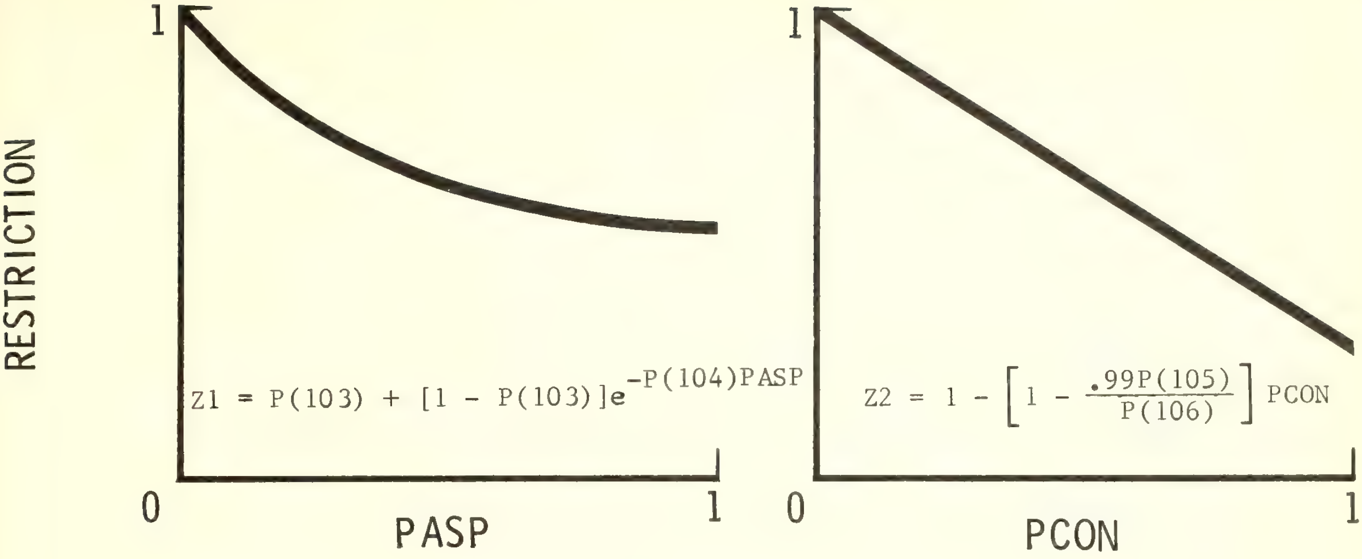


Figure 20.—Flow diagram depicting regeneration, growth, and mortality of conifer (CON).



FLOW 5 = CON * P(106) * Z1 * Z2

Figure 21.—Functions that inhibit the growth of conifer.

Production and mortality of annuals (code 43400–44700) are diagramed in figure 22. All other compartments affect production, but the conifer seedling effects are pooled into CONN and the aspen suckers act together with the shrubs. These restrictions are graphed in figure 23. Because the time step is 1 year, the relative mortality is 1. Sensitivity of the system to the various parameters in this portion of the program is very slight, and the herbs should probably not be subdivided into the two compartments.

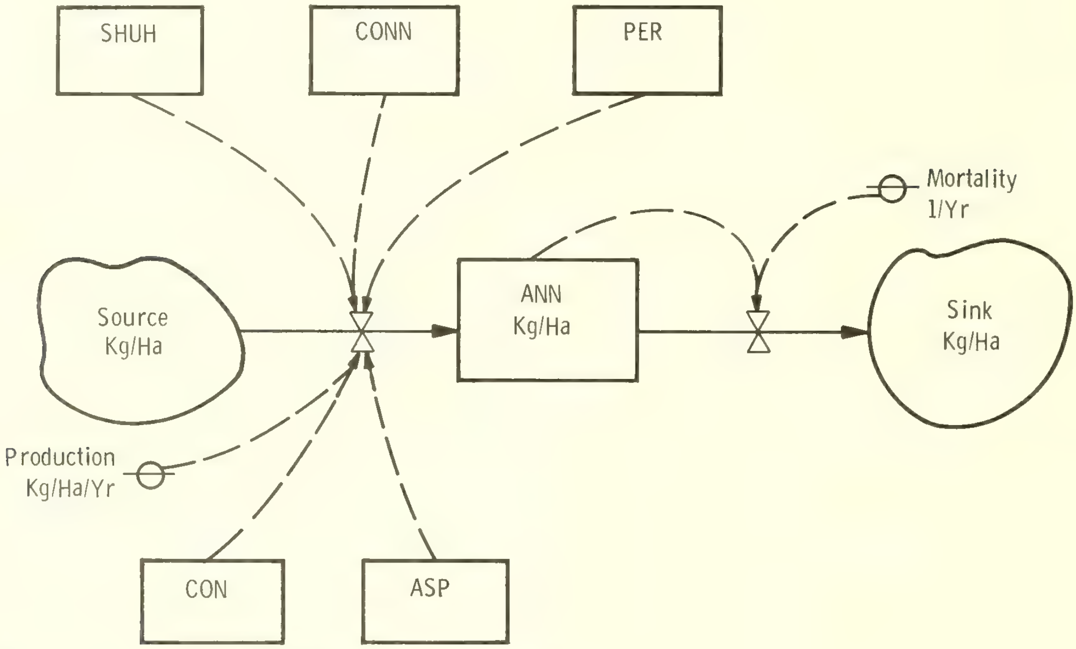
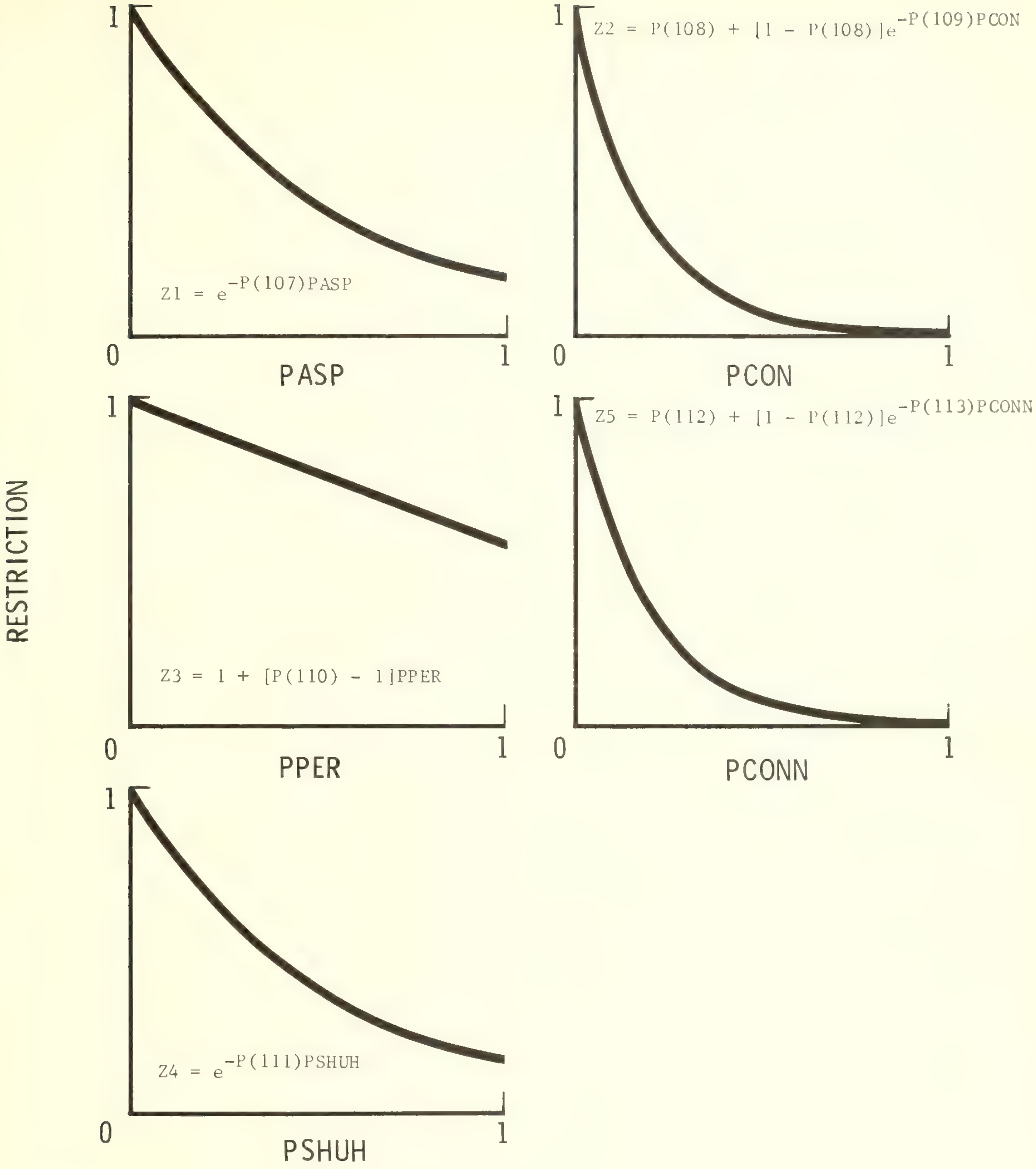


Figure 22.—Flow diagram depicting production and mortality of annuals.



FLOW 7 = P(114) * Z1 * Z2 * Z3 * Z4 * Z5

Figure 23.—Functions that inhibit the production of annual herbs.

Perennial production and mortality flows (code 44800–46100) are shown in figure 24. Since only the aboveground biomass is considered, mortality is considered to be 100 percent per annum. Restrictions on production are graphed in figure 25.

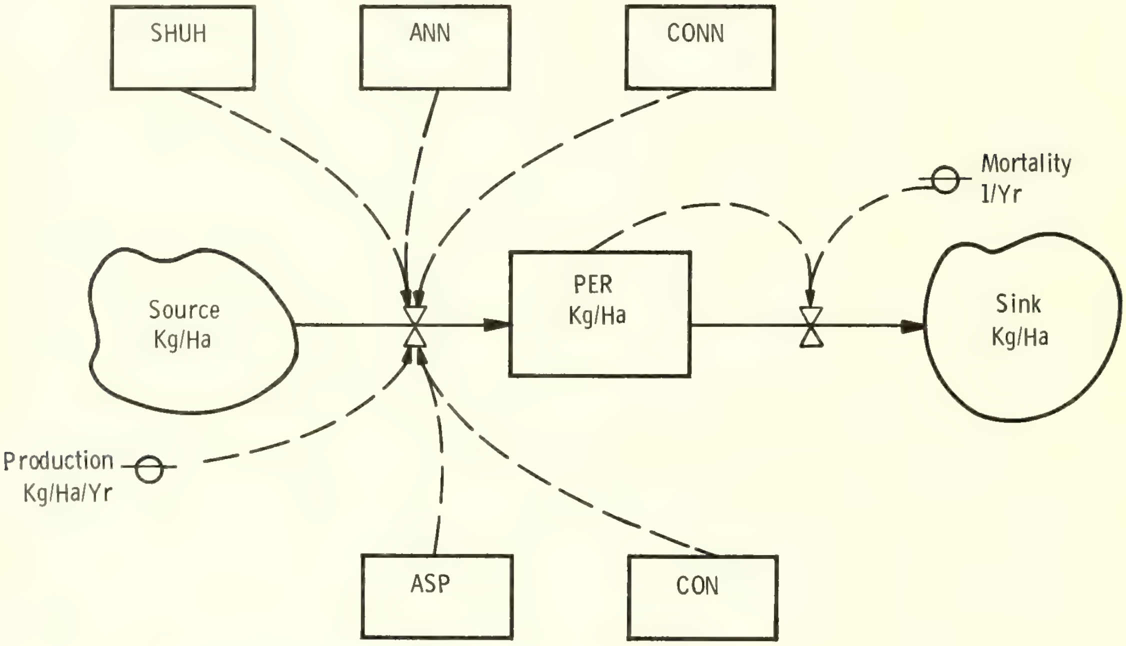
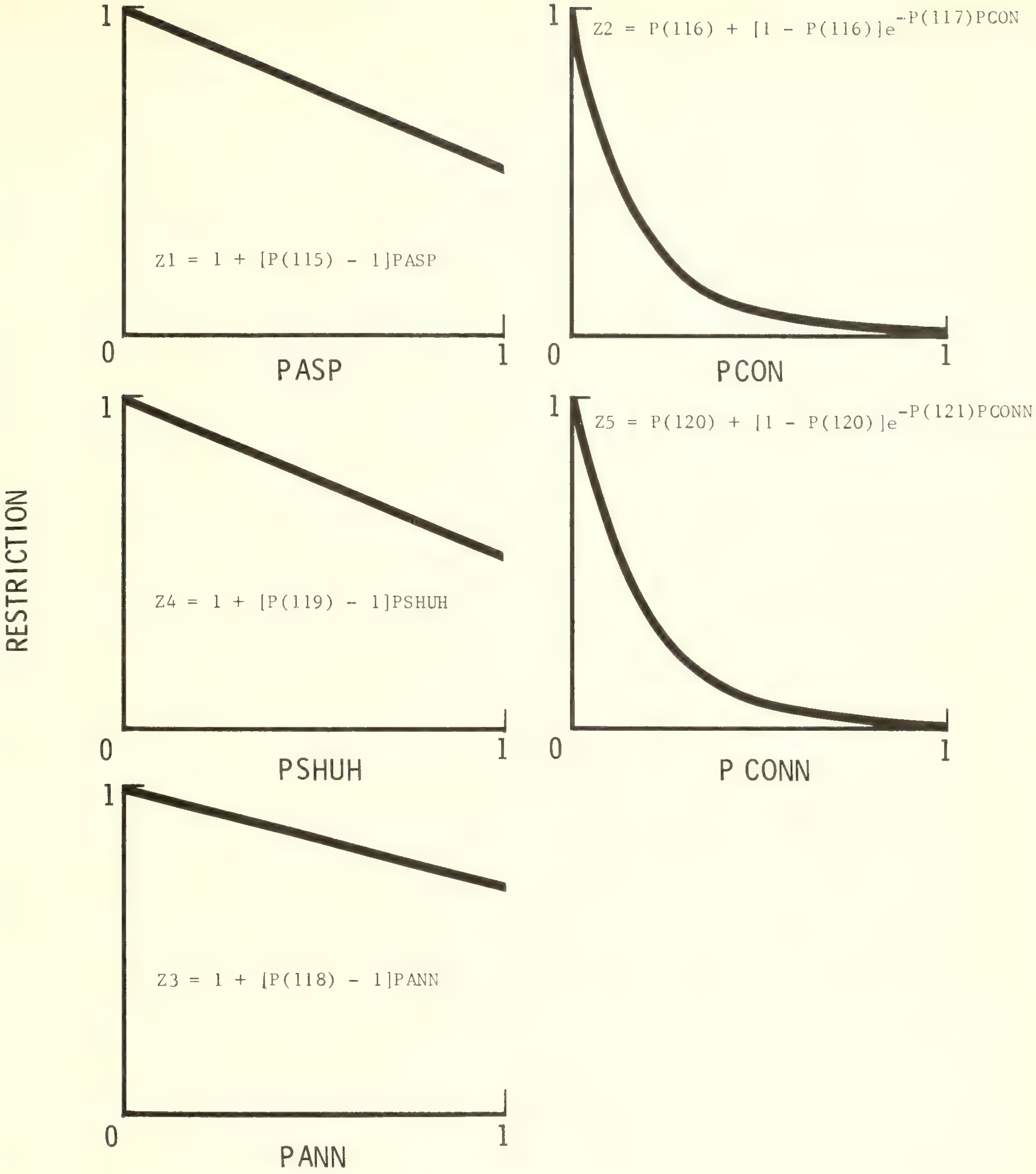


Figure 24.—Flow diagram depicting production and mortality of perennials.



FLOW 9 = P(122) * Z1 * Z2 * Z3 * Z4 * Z5

Figure 25.—Functions that inhibit the production of perennial herbs.

Regeneration, growth, and mortality (code 46200–48800) of shrubs are diagramed in figure 26 with restrictions shown in figures 27 and 28. Regeneration is on a biomass basis, rather than a numbers basis as it was for aspen and conifer reproduction. All compartments including the shrub compartment affect the regeneration rate. All compartments also inhibit the growth of shrubs, though effects of some are pooled. The restriction of shrubs on shrub growth is similar to that of aspen and conifer on their respective growths—net growth is blocked just prior to maximum possible biomass so that new input from regeneration will not raise the biomass beyond the maximum stated, as might happen if aspen and conifer were absent from the site.

After all the flows for one time step have been computed, time and the compartment values are updated (code 48900–53200). Thus, all values in one step are completely determined by the values in the preceding step, except that time may influence CON1 regeneration because a few years are required for seedlings to become established.

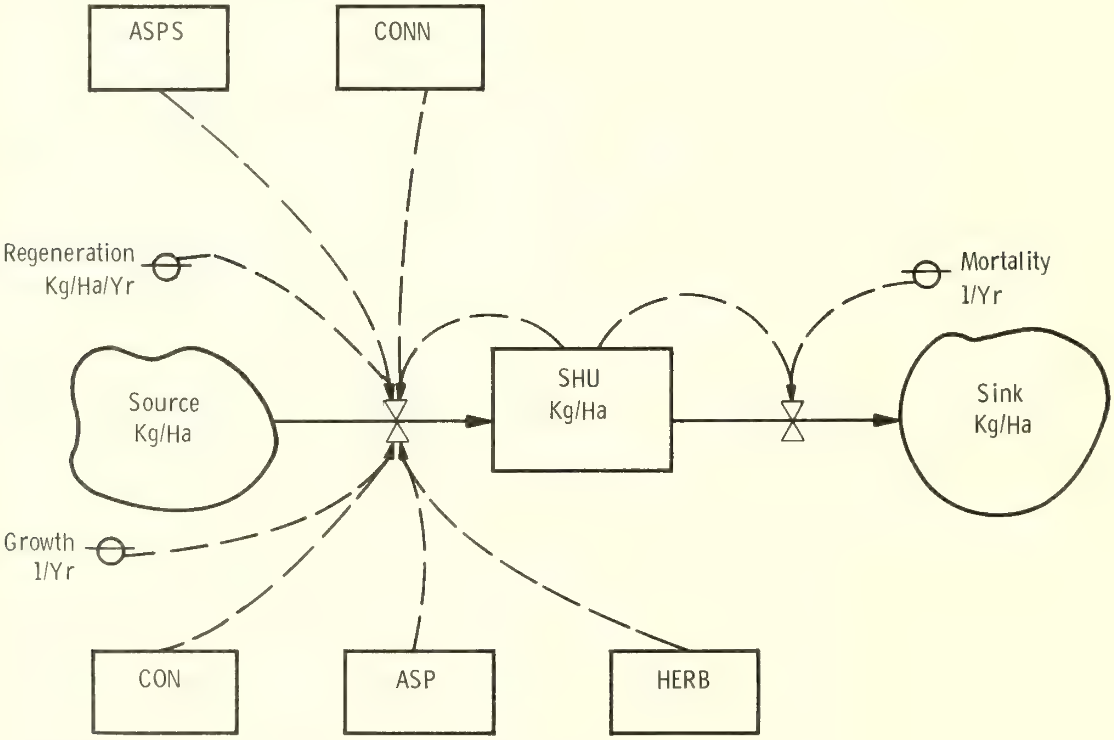
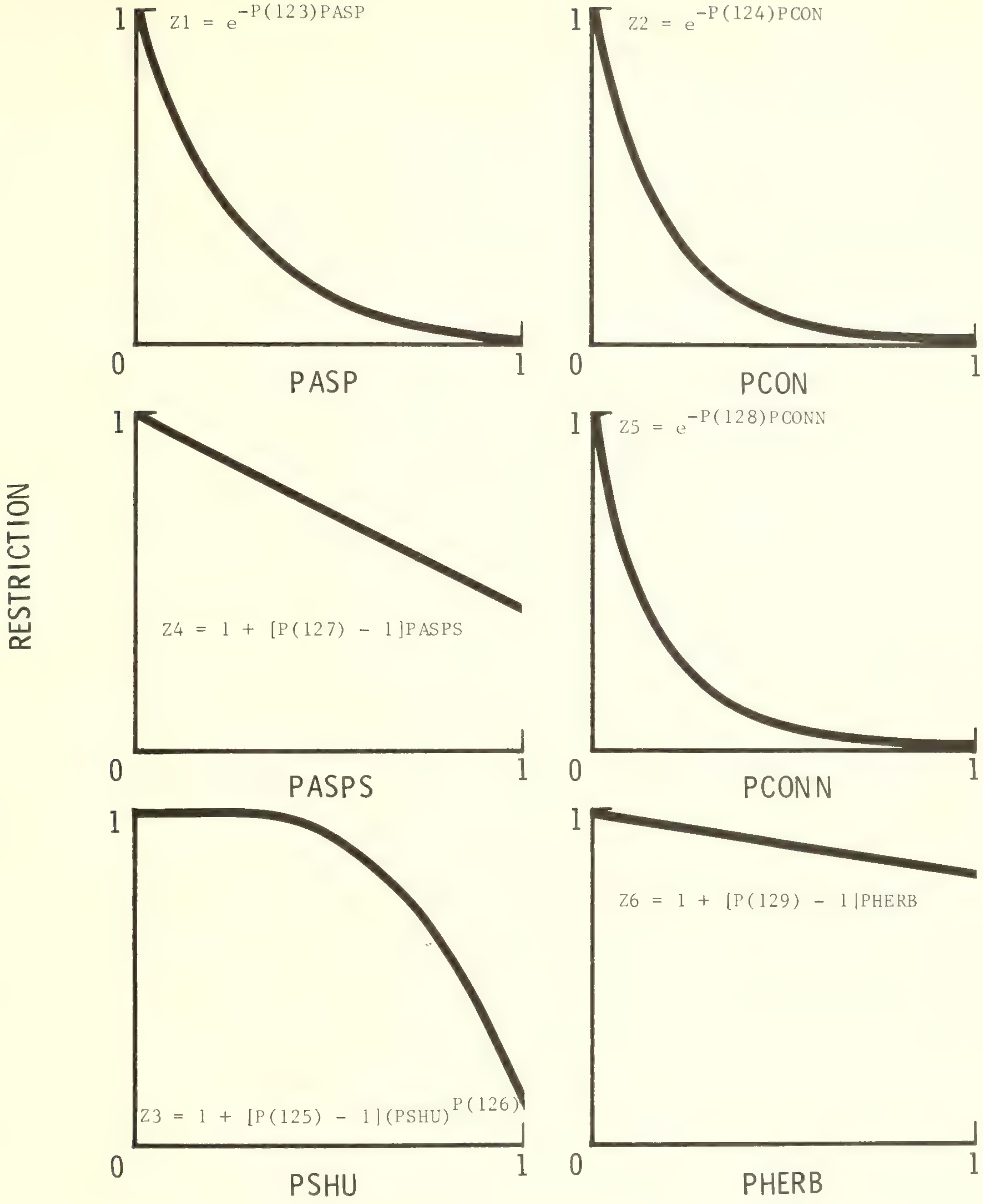
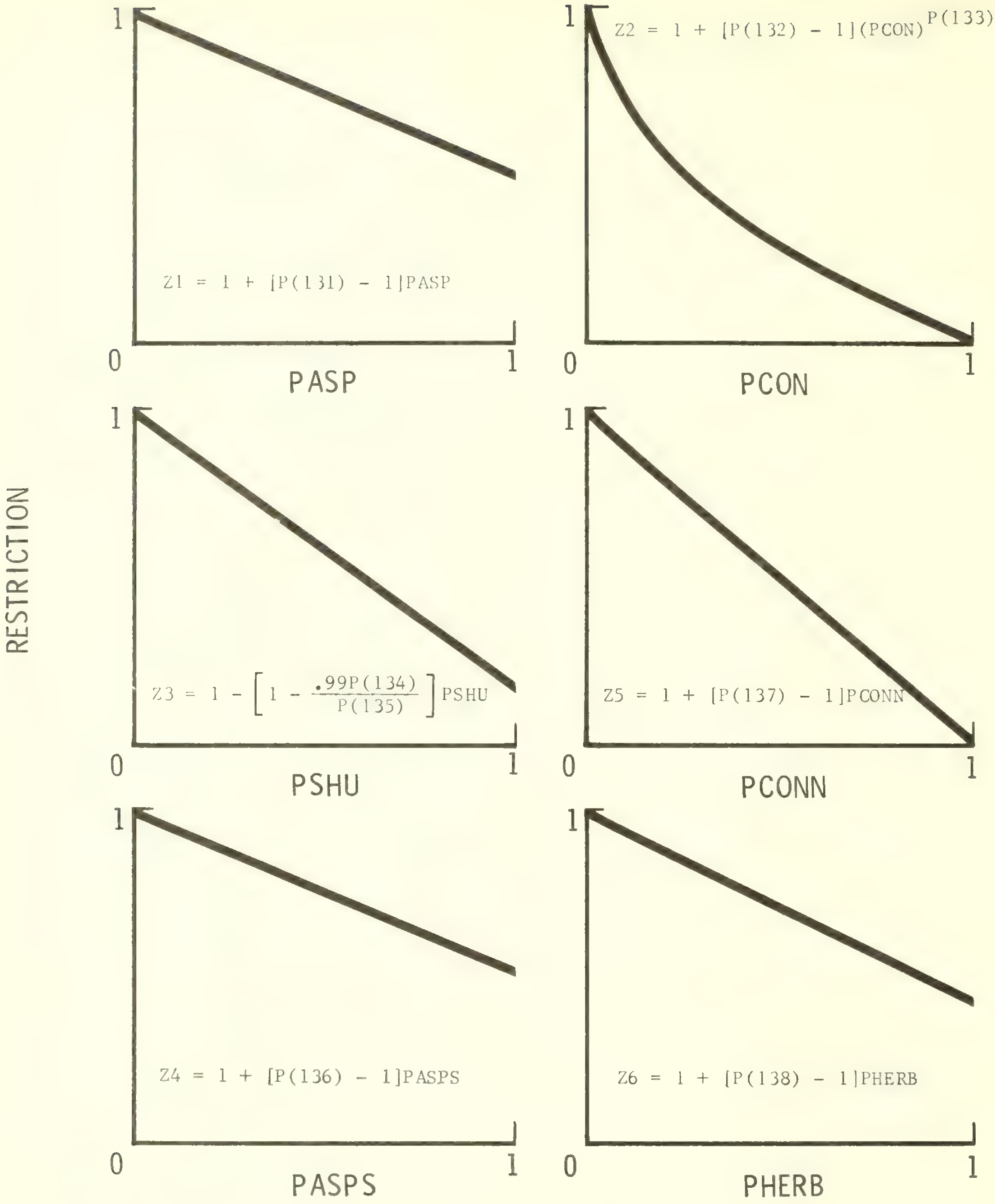


Figure 26.—Flow diagram depicting regeneration, growth, and mortality of shrubs.



FLOW 11 = P(130) * Z1 * Z2 * Z3 * Z4 * Z5 * Z6

Figure 27.—Functions that inhibit the regeneration of shrubs.



FLOW 12 = SHU * P(135) * Z1 * Z2 * Z3 * Z4 * Z5 * Z6

Figure 28.—Functions that inhibit the growth of shrubs.

MODEL RESULTS

The model results are quite realistic. Although no one has directly observed 400 years of succession in the Intermountain West, experts agree that the model output for a typical site fits their expectations developed from observations of a series of existing sites.

Results of the model for 400 years following a hot fire are shown in figure 29 (a, b, c). In this "standard run" it is assumed that maximum biomass possible for the major compartments is 200 000 kg/ha for aspen, 250 000 kg/ha for conifer, 10 000 kg/ha for shrubs, and 4 000 kg/ha for herbs. While peak aspen biomass (191 000 kg/ha) occurs in the 132d year, the aspen biomass exceeds 190 000 kg/ha for approximately 40 years. The conifers come in much more slowly and conifer biomass does not exceed aspen biomass until nearly 300 years after the disturbance. After 400 years the conifer biomass is 202 000 kg/ha and still increasing slightly. The shrubs peak in the 80th year with 7 050 kg/ha and herbs peak the eighth year with a biomass of 2 700 kg/ha. Graphs of biomass versus time for these major compartments are shown in figure 29a. Aspen suckers come in quite rapidly (fig. 29b), peaking within the first few years, but then they decline rapidly. The smallest size class (ASP1) is the most numerous. The number of conifer seedlings gradually increases to a peak value about 300 years following the disturbance and then decreases again, the small seedlings being more numerous (fig. 29c).

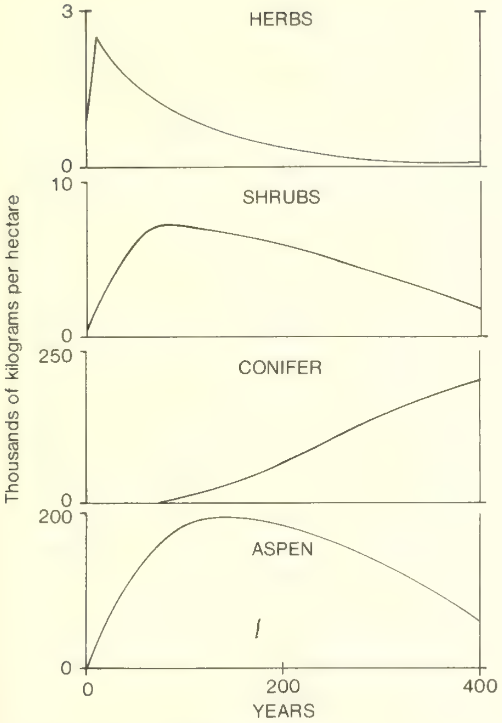


Figure 29a.—Biomass of four major system components graphed against time for "standard run" in which all parameters are at nominal levels.

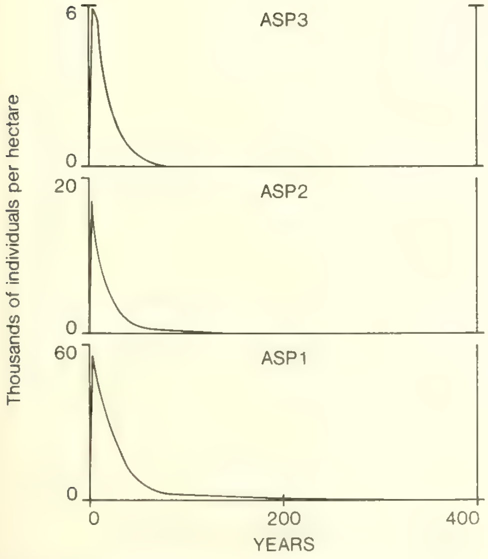


Figure 29b.—Density of three classes of aspen suckers graphed against time for "standard run" in which all parameters are at nominal levels.

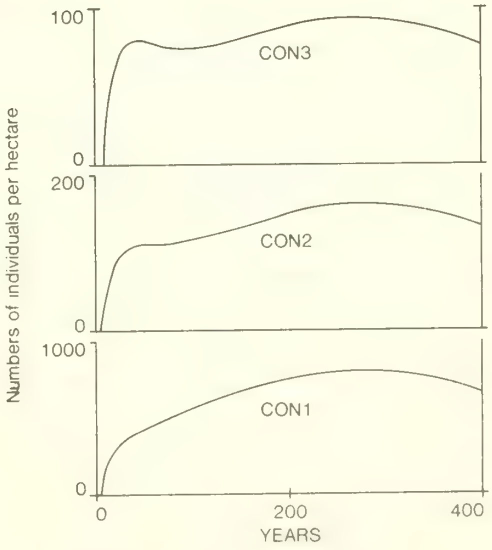


Figure 29c.—Density of three classes of conifer seedlings graphed against time for "standard run" in which all parameters are at nominal levels.

By changing the maximum rate at which conifer seedlings become established (parameter 79), from 1,000 to 10,000, an earlier dominance of conifers is obtained (fig. 30). This results in an earlier suppression of the other compartments and a shorter time period for conifers to approach maximum. Although such behavior may occur in the Intermountain area, it is probably more typical of aspen woodlands of the Upper Midwest.

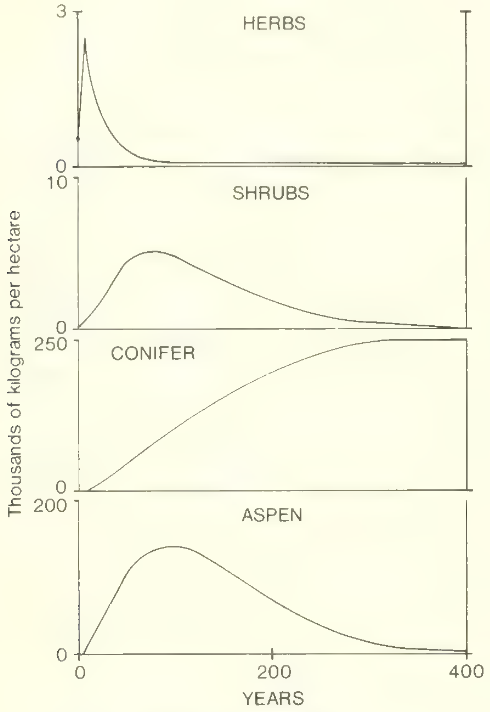


Figure 30.—Biomass of four major system components graphed against time for case simulating rapid regeneration of conifers.

If other disturbances are not allowed and if conifer seedlings do not become established (no seed source), the values in the other compartments remain much higher (fig. 31) throughout the simulation run.

In figure 32 an aspen harvest is simulated at 90 years in the successional process to favor conifer production on the site. Conifer growth is shown to be enhanced by that harvest; in just 270 years it attains the value achieved in 400 years in the "standard run," and after 400 years it is close to its maximum biomass. Immediately after the aspen harvest, the shrubs and herbs increase but are quickly suppressed again by the rapidly growing conifers. Aspen comes in again after the harvest but peaks at only 85 000 kg/ha and is almost eliminated by the 400th year. Aspen regeneration is stimulated by the harvest of aspen overstory, but establishment of conifer seedlings is suppressed (fig. 33). This situation brings up a controversial point in the model: the effect of aspen on conifer seedling regeneration. Foresters differ as to the influence of aspen on conifer regeneration, and it was decided to use a positive influence in this model. This positive effect on conifer regeneration is partially due to the ameliorating effects aspen has on soil surface temperatures (Sperger 1980). It is accomplished by having the aspen restriction on conifer regeneration **decrease** as aspen

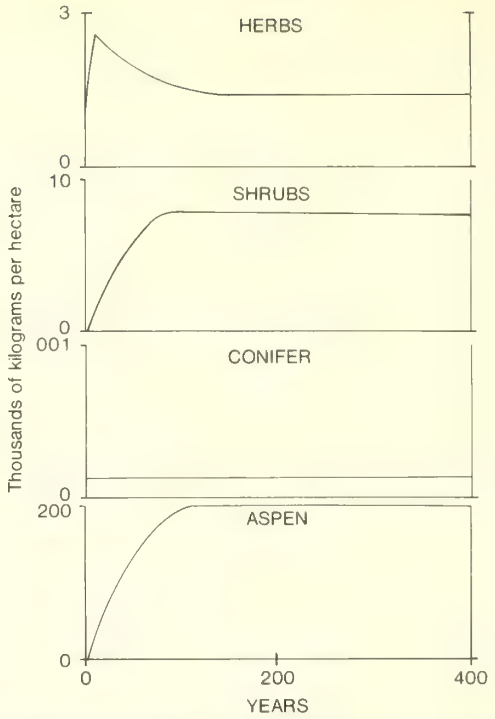


Figure 31.—Biomass of four major system components graphed against time for case in which there is no conifer regeneration.

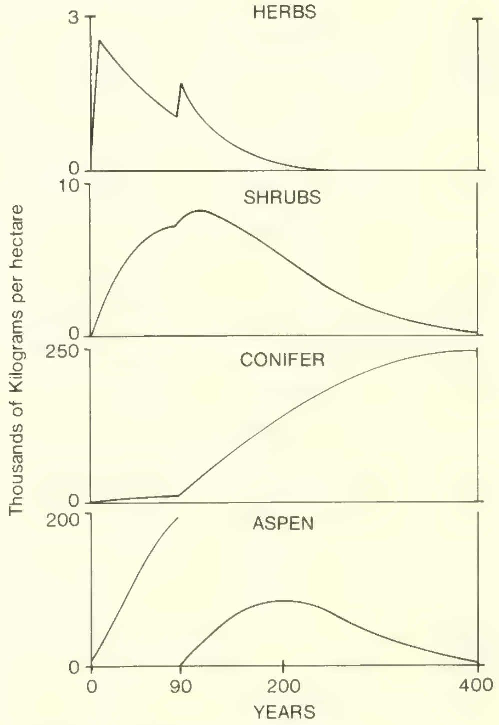


Figure 32.—Biomass of four major system components graphed against time for case in which aspen is harvested at 90 years.

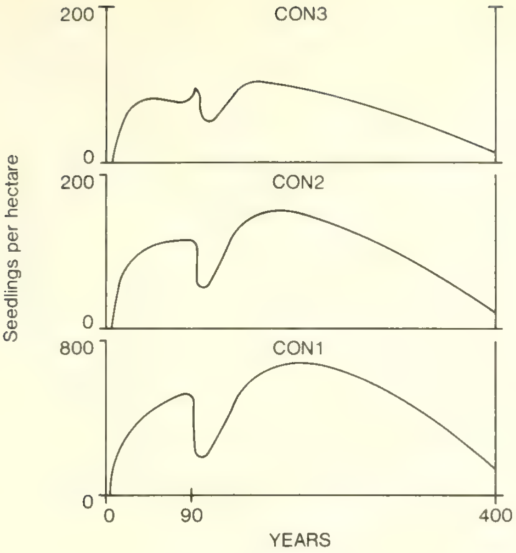


Figure 33.—Density of conifer seedlings in case where aspen overstory is harvested at 90 years.

biomass increases. Thus, harvest of the aspen overstory imposes a restriction on the regeneration of conifer. This influence merits further investigation. However, even if no influence of aspen on conifer regeneration is allowed, the conifer biomass in the 300th year is only 1.9 percent higher for the " standard run," while peak biomass for shrubs, aspen, and herbs changes very little.

A more typical clearcutting situation is shown in figure 34. Here all the overstory conifers and half the conifer seedlings are removed at 300 years. Also, half the mature aspen biomass is removed by harvesting. The next 300 years are very similar to the first 300 except that aspen peaks a little more quickly and at a somewhat higher value. One should bear in mind that this second peak does not represent the even-aged stand represented by the first peak.

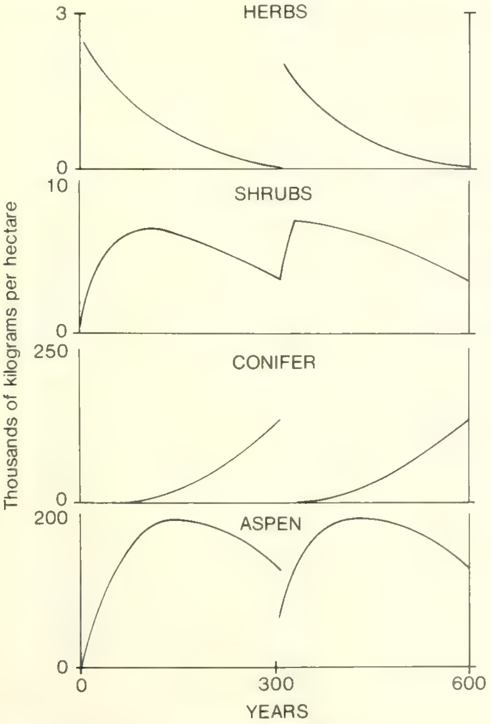


Figure 34.—Biomass of four major system components graphed against time for case in which conifer and aspen are harvested at 300 years.

The major shortcoming of the model is lack of confidence in the parameter values used. It is quite possible that widely differing sets of parameters can give very similar model results. On the other hand, slightly differing parameters can yield widely differing results. To demonstrate the degree of uncertainty in the model, 32 simulation runs (variations on the " standard run") were made. Parameters for the maximum production rates of annuals and perennials and for the maximum values of the aspen, conifer, shrub, annual, and perennial compartments were fixed for the "typical" site investigated and the initial value for number of conifers was held at zero. At the start of each of these 32 runs, each of the remaining 130 parameter values was picked at random from a uniform distribution over the range of values considered possible for that parameter (appendix C) and held for the duration of the run. Choice of parameters was not always completely random, however; checks were made to ascertain that the sum of relative flow rates from a compartment did not exceed 1 and that aspen growth rate never exceeded the conifer growth rate. The basic shapes of the resulting graphs were much the same in all cases. That is, if appropriately different scales were used for the 32 graphs of any major compartment, they would be quite similar in appearance. Some idea of the distribution of these 32 runs can be gained from figure 35, which shows for each point in time the minimum and maximum values of each of the four major compartments as well as the 25th, 50th, and 75th percentile values.

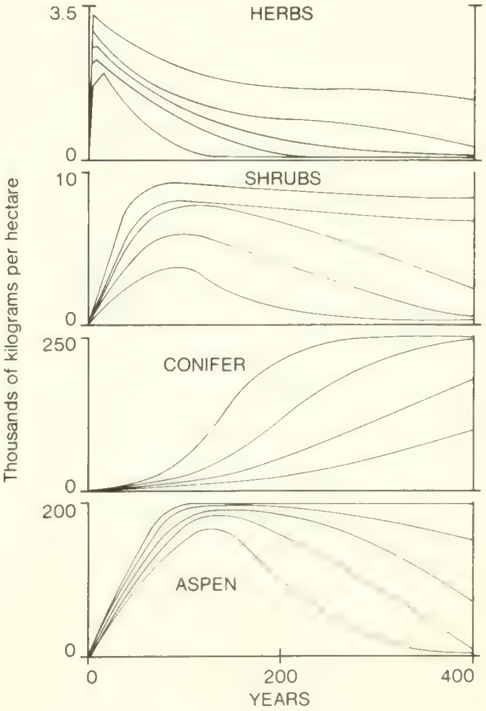


Figure 35.—Results from 32 computer runs with randomly varying parameters showing maximum, 75th percentile, 50th percentile, 25th percentile, and minimum values at each point in time.

Sensitivity Analysis

To test parameter sensitivity, the same 130 parameters mentioned in the preceding section were altered one at a time from the nominal value to the more remote end point in the range of possible values. Change in the peak value for each of the four major compartments was recorded, as was the change in time at which the peak occurred. This exercise showed that the model is fairly insensitive to changes in many of the parameters, indicating that the model may be overdetermined; however, it is still quite sensitive to changes in others. The change in time at which peaks occurred varied little, and the peak biomass of herbs also did not indicate much sensitivity except to the initial value of annuals. Parameters to which the peak values of aspen, conifers, and shrubs are most sensitive are those involving the growth and mortality rates of those compartments, the restriction of aspen on conifer growth, the restriction of conifers on aspen growth, and regeneration into or mortality from CON1. For instance, an increase in the annual growth rate of conifers from 7 percent to 7.5 percent reduces the peak value of aspen biomass by 0.7 percent and increases the peak conifer biomass by 19.7 percent. If the maximum restriction of aspen on conifer growth is lessened from 0.5 to 0.7, the peak aspen biomass is decreased 3.1 percent while the peak conifer biomass is increased 70.9 percent.

Further investigations of these relationships indicated that one could raise conifer growth rates from 7 percent to 8 percent, raise conifer mortality from 2 to 3 percent, lighten the restriction of aspen on conifer growth from 0.5 to 0.5625, and get almost no change at all in the model results! Therefore, the parameter values are not unique, but it appears that, so long as there is some method of bringing growth and mortality rates together, the conifer biomass will show appropriate sigmoidal growth.

Some two-way interactions were also tested. The three indicators chosen were peak aspen and peak shrub biomass in 400 years and conifer biomass at 300 years. Because graphs of a compartment's size are very similar if scales are adjusted appropriately, it was felt that maximum values would be good indicators. Because the peak of herbs is almost never affected, it was dropped as an indicator. Peak conifer biomass always occurred at 400 years and differences at that time could be slight while differences earlier were much greater; so biomass at 300 years was a more appropriate indicator for conifer biomass.

Of the 130 parameters allowed to vary it was found that 32 caused at least 1 of those 3 indicators to change from its nominal value by at least 2 percent (table 1). For these 32 parameters, all 496 paired interactions were evaluated. For I, I(A), I(B), and I(AB) (defined, respectively, as the values of the

Table 1.—Parameters (identified in appendix C) to which the ASPEN model is most sensitive, their nominal and perturbed values, and the effect of those perturbations on the three indicators

Parameter number	Nominal value	Perturbed value	Peak aspen % change	Conifer at 300 % change	Peak shrub % change
13	15000.	20000.	-0.3	2.8	-2.0
67	.03	.035	-1.9	4.7	2.0
70	1.2	1.4	1.2	-2.6	-.1
77	.2	.4	-.4	3.6	-.4
78	.001	.2	-.7	3.8	-.8
79	1000.	1250.	-.9	7.6	-.8
80	5.	10.	.4	-3.4	.7
81	.7	.9	.6	-7.0	.6
82	.5	.7	-.3	4.1	-.2
87	.7	.9	-.2	2.3	-.2
88	.7	.9	-.3	2.5	-.3
89	.3	.4	-.9	7.8	-.8
90	.45	.6	.6	-7.1	.6
91	.5	.7	-.3	3.8	-.2
97	.25	.4	-1.3	10.8	-1.2
98	.1	.15	.5	-6.0	.5
99	.5	.7	-.2	2.6	-.2
101	.2	.3	-.6	5.8	-.9
102	6.	7.	-.6	3.7	-.7
103	.5	.7	-3.1	70.9	-1.5
104	3.	4.	.4	-13.6	.3
105	.02	.025	1.0	-42.5	.6
106	.07	.075	.7	19.7	.4
115	.5	.7	.3	-2.9	-4.8
119	.5	.4	3.1	-3.1	-2.6
123	4.	6.	.0	.4	-2.3
130	100.	125.	.1	-.5	2.6
131	.5	.6	.0	-.8	8.3
133	.5	1.	.1	-1.5	10.6
134	.03	.04	-.1	1.9	-17.9
135	.2	.25	.2	-2.0	14.2
138	.4	.6	.1	-1.2	9.3

indicator with no parameters perturbed, only parameter A perturbed, only parameter B perturbed, and both A and B perturbed), the effect of the interaction of A with B is defined to be [I(AB) – I] – [I(A) – I] – [I(B) – I]. In only 24 of these 496 cases did effect of the interaction on an indicator exceed 2 percent of the nominal value of the indicator. In every case it was the 300-year biomass of the conifer that was changed by at least 2 percent. In 20 of the 24 cases the parameter giving the maximum restriction of aspen on conifer growth was involved. The other four cases involved growth or mortality of aspen or conifer. In none of the cases investigated did the effect of the interaction exceed the larger of the two main effects. Because parameters having the greatest effect on the indicators were investigated, it is likely that a similar result would have held if the other 5,000+ pairs had been checked. Thus, the strongest interactions affecting the selected indicators probably are the 24 listed in table 2.

The main effects and interactions previously mentioned involved altering just one or two parameters at a time. Another concept of effect involves a factorial design in which all combinations of parameters are perturbed and the average effect over all combinations of other factors is considered. (A discussion of factorial designs and fractional factorial designs can be found in Cochran and Cox, 1975.) A complete factorial design for 130 factors, or even 30 factors, would have been too expensive; however, a fractional factorial design for a set of 36 parameters, which included the 32 previously found to have the largest main effects, was possible. These were divided into six groups called macroparameters because each is treated as a unit in the factorial analysis. These macroparameters, named A, B, C, D, E, and F, contain six parameters each. Care was taken to separate closely related parameters into different macroparameters. Then a 0.5 replication of a 2**6 factorial design was done using ABCDEF as the defining contrast. The three indicators of interest were again the peak values of aspen and shrubs over 400 years and the value of conifer at 300 years. Contents of the macroparameters are shown in table 3. The ones perturbed in each repetition of the experiment and corresponding values of the three indicators are shown in table 4.

The effect of a factor on an indicator is defined to be 1/32 of the sum of all values of that indicator obtained from experiments in which an odd number of the macroparameters within that factor were perturbed, minus 1/32 of the sum of all values of the indicator obtained from experiments in which an even number of the macroparameters within that factor were perturbed. Each main effect has an alias with a 5-way interaction; each 2-way interaction has an alias with a 4-way interaction; and each 3-way interaction has an alias with another 3-way interaction. The various factors, their aliases, corresponding change, and percentage change in values of the three indicators are given in table 5. From this table one can observe that for all three indicators the effects of the 1-way (5-way) interactions are in general greater than the effects of the 2-way (4-way) interactions, which are in general larger than the effects of the 3-way interactions. This observation and intuition indicate that the larger effects are associated with the lower rather than the

Table 2.—Parameter pairs to which the system is most sensitive, their nominal and perturbed values, and the effect of each perturbation, due to the interaction, on the conifer biomass in the 300th year

Parameter number	Nominal value	Perturbed value	Parameter number	Nominal value	Perturbed value	Percent change in CON (300) due to interaction
13	15000.	20000.	103	0.5	0.7	-2.2
67	.03	.035	104	3.	4.	-2.2
67	.03	.035	105	.02	.025	-2.4
67	.03	.035	106	.07	.075	2.1
77	.2	.4	103	.5	.7	-2.7
78	.001	.2	103	.5	.7	-3.7
79	1000.	1250.	103	.5	.7	-5.6
80	5.	10.	103	.5	.7	2.1
81	.7	.9	103	.5	.7	5.1
82	.5	.7	103	.5	.7	-3.3
89	.3	.4	103	.5	.7	-5.8
90	.45	.6	103	.5	.7	5.2
91	.5	.7	103	.5	.7	-3.1
97	.25	.4	103	.5	.7	-8.1
98	.1	.15	103	.5	.7	4.5
99	.5	.7	103	.5	.7	-2.1
101	.2	.3	103	.5	.7	-4.3
102	6.	7.	103	.5	.7	-3.8
103	.5	.7	104	3.	4.	8.1
103	.5	.7	105	.02	.025	23.3
103	.5	.7	106	.07	.075	-14.5
103	.5	.7	119	.5	.7	2.1
103	.5	.7	115	.5	.7	2.1
104	3.	4.	105	.02	.025	3.8

higher order interactions. In other words this fractional factorial design serves to reinforce the previous results determining which parameters the system is most sensitive to without giving as much detail. The effect of a macroparameter corresponds roughly to the effects of its constituent parts but is not the mean of those separate effects.

Table 3.—Elements of a macroparameter used in the fractional factorial design

Macroparameter	Parameters					
A	36	68	97	104	115	135
B	70	80	82	98	130	134
C	13	67	77	88	99	123
D	58	78	89	101	106	133
E	32	79	90	102	103	131
F	71	81	91	105	119	138

Table 4.—Treatment combinations in the fractional factorial design and corresponding values of the three indicators

Treatment combinations	Peak aspen biomass	Conifer biomass at 300 years	Peak shrub biomass
none	191431.	136588.	7050.
AB	195503.	118820.	6928.
AC	187023.	143652.	7497.
AD	187145.	165280.	8307.
AE	185432.	230285.	8005.
AF	195483.	62685.	8181.
BC	189827.	147357.	5792.
BD	190058.	172190.	6975.
BE	188938.	230019.	6646.
BF	196333.	67952.	6944.
CD	172764.	211782.	7859.
CE	171980.	243178.	7198.
CF	189226.	92279.	7522.
DE	171926.	244791.	8316.
DF	189439.	121772.	8175.
EF	188281.	206687.	7974.
ABCD	184586.	175282.	7593.
ABCE	183182.	235315.	7121.
ABCF	194369.	80309.	7514.
ABDE	183155.	238680.	8150.
ABDF	194563.	105379.	8065.
ABEF	193766.	190216.	7968.
ACDE	158185.	247128.	8679.
ACDF	182953.	129373.	8621.
ACEF	181381.	215800.	8325.
ADEF	181111.	225440.	8884.
BCDE	167716.	246617.	7526.
BCDF	186895.	134833.	7472.
BCEF	185712.	214236.	7136.
BDEF	185898.	225754.	7990.
CDEF	162565.	243121.	8545.
ABCDEF	177484.	232844.	8444.

Table 5.—Factors, their aliases, and interactive effects on the three indicators as determined by the fractional factorial design

Defining contrast ABCDEF		Peak aspen biomass		Conifer biomass at 300 years		Peak shrub biomass	
Factor	Alias	Effect	% from nominal	Effect	% from nominal	Effect	% from nominal
A	BCDEF	1135.	0.6	-4458.	-3.3	286.	4.1
B	ACDEF	3177.	1.7	-3251.	-2.4	-340.	-4.8
C	ABDEF	-4457.	-2.3	7830.	5.7	-54.	-.8
D	ABCEF	-4419.	-2.3	15778.	11.6	369.	5.2
E	ABCDF	-5028.	-2.6	50143.	36.7	200.	2.8
F	ABCDE	2394.	1.3	-19946.	-14.6	254.	3.6
AB	CDEF	-183.	-.1	576.	.4	45.	.6
AC	BDEF	270.	.1	-148.	-.1	10.	.1
AD	BCEF	235.	.1	-633.	-.5	-44.	-.6
AE	BCDF	157.	.1	2040.	1.5	-21.	-.3
AF	BCDE	-88.	0.	422.	.3	-21.	-.3
BC	ADEF	804.	.4	-469.	-.3	-13.	-.2
BD	ACEF	840.	.4	-318.	-.2	17.	.2
BE	ACDF	885.	.5	579.	.4	31.	.4
BF	ACDE	-391.	-.2	399.	.3	46.	.7
CD	ABEF	-1178.	-.6	-224.	-.2	46.	.7
CE	ABDF	-1187.	-.6	-2432.	-1.8	-6.	-.1
CF	ABDE	439.	.2	727.	.5	16.	.2
DE	ABCF	-1245.	-.7	-7113.	-5.2	16.	.2
DF	ABCE	442.	.2	2244.	1.6	-79.	-1.1
EF	ABCD	461.	.2	9827.	7.2	-27.	-.4
ABC	DEF	-38.	0.	1618.	1.2	2.	0.
ABD	CEF	-34.	0.	1113.	.8	-2.	0.
ABE	CDF	56.	0.	-604.	-.4	-12.	-.2
ABF	CDE	-196.	-.1	-793.	-.6	-4.	-.1
ACD	BEF	19.	0.	-1227.	-.9	-11.	-.2
ACE	BDF	-30.	0.	558.	.4	-5.	-.1
ACF	BDE	157.	.1	917.	.7	3.	0
ADE	BCF	-48.	0.	1027.	.8	1.	0.
ADF	BCE	132.	.1	614.	.4	7.	.1
AEF	BCD	206.	.1	-1190.	-.9	3.	0.

Use of the Program

To run the program ASPEN one must specify from which device to read the data and on which device to print the results. Appendix A contains a listing of the program as it is run with a card deck at Utah State University (USU) and the input device, file 5, is specified as the card reader while the output device on file 6 is specified as the printer (code 200–300).

A brief flow chart of the program is given in figure 36. It does not describe the flow equations in detail because they are handled in the section on model structure.

The first information required from the data file concerns time. The values of DT, TEND, STEP, and PSTSZ are read and then printed as part of the program output (code 9300–9900). DT is the step size of the difference equations. Although it is a parameter, it was always used as 1 year in our work at USU. While it is conceivable that one might want to increase step size to save computation, some of the parameters would need to be altered to compensate. For instance, a growth rate of 8 percent per year is not quite the same as a growth rate of 16 percent over 2 years, and the difference can be pronounced after 400 years. The length of the run in years is TEND; the number of years between printout of state variables is STEP; and PSTSZ specifies the number of years between points on the graphical output. The graphing subroutines (code 56000–65200) allow for only 101 points (including the point at time 0) plotted across the page; so PSTSZ must be an integer no smaller than the quotient TEND divided by 100. In a run of 100 years or fewer, each year's values can be graphed, but for a run of 400 years, no more than every fourth year can be graphed (PSTSZ = 400/100 = 4 or larger). The printed output is fairly voluminous, and printing every year's values can be expensive. A sample output is shown in appendix B.

Immediately following the time information are the 138 parameter values. The program reads these values and prints them with the other output (code 10000–11000). Parameter values are read in free format, five to the line. The last two values, P(139) = P(140) = 0, are simply space fillers. It is not easy to find a particular value from the listing, but it is possible if it is remembered that the four values on the first line are for time and that the parameter values follow in order, five to the line.

Time is always initiated at zero by the program. If the program is stopped and restarted again at a later year, the later year does not show up in the output; time is reinitiated to zero. The time delay for conifer seedling establishment, parameter 80, tells how many years into the run to delay. For example if the run is stopped for some reason and restarted at 100 years and if a 5-year time delay on conifer seedling establishment is desired, parameter 80 should be set at 5, not 105.

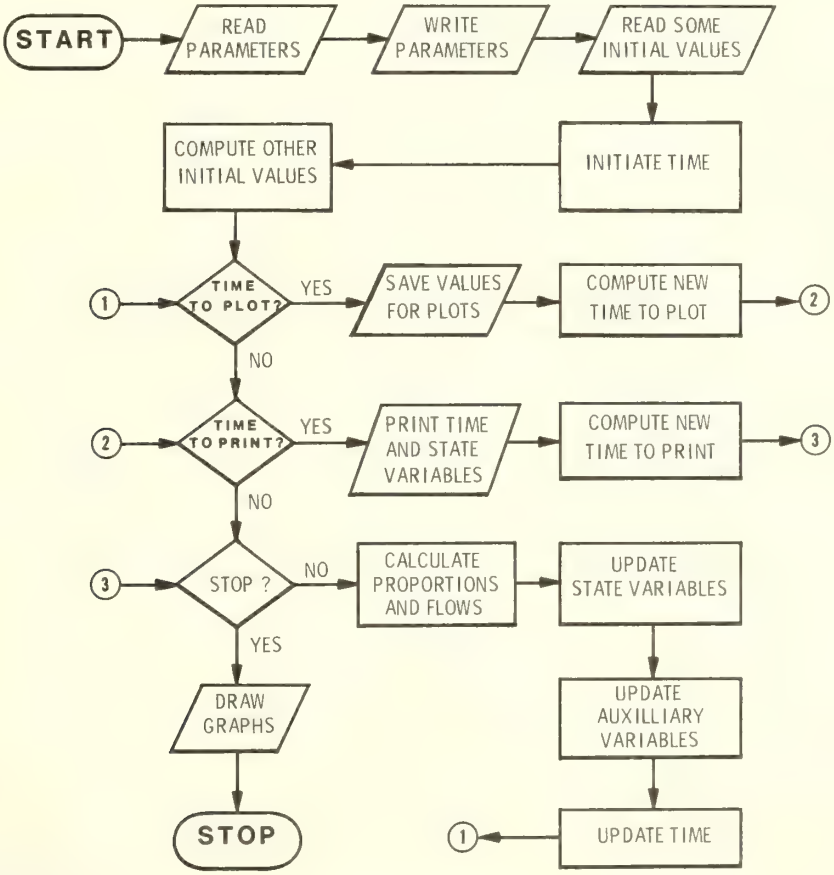


Figure 36.—A brief flow chart of the program ASPEN.

CONCLUSIONS

For trajectory analysis of orbiting satellites, a flat-earth theory is woefully inadequate, but for consideration of baseball trajectories at a ball park, that theory is quite adequate. Similarly, the succession model presented in this paper, while certainly incomplete, might help a land manager identify the successional stage of a forest and determine how its composition might change in the future.

The model yields believable results for the forest system simulated, whether that forest was undisturbed or subjected to various manipulations. It could be of some aid in making forest management decisions if managers bear in mind that the model is a partial truth and not the whole truth.

The distressing shortcoming of the model is that good estimates do not exist for most of the parameters used. Many parameter values were chosen from a range which scientists in our project estimated to include the actual value. To some of these parameters the model is quite sensitive, giving vastly different simulation results depending on which value in that range is chosen. One should not rely on the model as a predictor until closer estimates of these parameters are obtained.

Sensitivity analysis has also shown that the model is quite insensitive to many parameter estimates, indicating that a simplification effort might substantially reduce the model complexity while keeping the essential features. We have also isolated those parameters (growth and mortality rates of aspen and conifer and the restrictive effect of aspen on conifer growth) that have the most drastic effects on the model output. Further research in these areas would be most valuable to our understanding of the system and would lend confidence to the model as a predictive tool.

PUBLICATIONS CITED

Baker, F. S. Aspen in the central Rocky Mountain Region. Bull. 1291. Washington, D.C.: U.S. Department of Agriculture; 1925. 47 p.

Bartos, D. L. A dynamic model of aspen succession. In: IUFRO Biomass Studies. Orono, ME: University of Maine Press; 1973: 11-15.

Bartos, D. L. Modeling plant succession in aspen ecosystems. In: Hyder, D. N., ed. Proceedings, 1st International Rangeland Congress; Denver, CO. Denver, CO: Society for Range Management; 1978: 208-211.

Bartos, D. L.; Johnston, R. S. Biomass and nutrient content of quaking aspen at two sites in the western United States. For. Sci. 24(2): 273-280; 1978.

Bartos, D. L.; Mueggler, W. F. Early succession in aspen communities following fire in western Wyoming. J. Range Manage. 34(4): 315-318; 1981.

Botkin, D. B. Life and death in a forest: the computer as an aid to understanding. In: Hall, C. A. S.; Day, J. R., eds. Ecosystem modeling in theory and practice: an introduction with case histories. New York: Wiley and Sons; 1977: 213-233.

Botkin, D. B.; Janek, J. F.; Wallis, J. R. Rationale, limitations, and assumptions of a northeastern forest growth simulator. IBM J. Res. Develop. 16(2): 101-116; 1972a.

Botkin, D. B.; Janek, J. F.; Wallis, J. R. Some ecological consequences of a computer model of forest growth. J. Ecol. 60: 948-972; 1972b.

Cochran, W. G.; Cox, G. M. Experimental designs. New York: Wiley and Sons; 1975. 611 p.

Innis, G. Simulation of ill-defined systems. Some problems and programs. Simulation Today. 9: 33-36; 1972.

Little, E. L. Atlas of United States trees. Vol. 1. Conifers and important hardwoods. Misc. Publ. 1146. Washington, D.C.: U.S. Department of Agriculture, Forest Service; 1971. 1146 p.

Long, J. N.; Turner, J. Aboveground biomass of understory and overstory in an age sequence of four Douglas-fir stands. J. Appl. Ecol. 12: 179-188; 1975.

Mueggler, W. F. Type variability and succession in aspen ecosystems. In: Utilization and marketing as tools for aspen management in the Rocky Mountains. Gen. Tech. Rep. RM-29. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station; 1976: 16-19.

Mueggler, W. F.; Bartos, D. L. The Grindstone Flat and Big Flat exclosures—a 41-year record of changes in clearcut aspen communities. Res. Pap. INT-195. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1977. 16 p.

Noble, I. R.; Slatyer, R. O. Post-fire succession of plants in Mediterranean ecosystems. In: Proceedings of the symposium on the environmental consequences of fire and fuel management in mediterranean climate ecoystems. Gen. Tech. Rep. WO-3. Washington, DC: U.S. Department of Agriculture, Forest Service; 1977: 27-36.

Noble, D. L.; Ronco, F., Jr. Seedfall and establishment of Engelmann spruce and subalpine fir in clearcut openings in Colorado. Res. Pap. RM-200. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station; 1978. 12 p.

Odum, H. T. Analyzing and modeling grassland biomass. BioScience. 31(10): 766-767; 1981.

Rodin, L. E.; Bazilevich, N. I. Production and mineral cycling in terrestrial vegetation. Edinburgh and London: Oliver and Boyd; 1967. 288 p.

Shugart, H. H.; West, D. C. Development of an Appalachian deciduous forest succession model and its application to assessment of the impact of the chestnut blight. J. Environ. Manage. 5: 161-179; 1977.

Shugart, H. H.; West, D. C. Forest succession models. BioScience. 30: 308-313; 1980.

Sperger, R. H. A simulation model of secondary forest succession in an Engelmann spruce (*Picea engelmannii* Parry)—subalpine fir (*Abies lasiocarpa* [Hook] Nutt.) ecosystem. Logan, UT: Utah State University; 1980. 239 p. M.S. thesis.

Trimble, J. L.; Shriner, C. R. Inventory of United States Forest Growth Models. ORNL/Sub-80/13819/1. Oak Ridge, TN: Oak Ridge National Laboratory; 1981. 133 p.

Youngblood, A. P.; Mueggler, W. F. Aspen community types on the Bridger-Teton National Forest in western Wyoming. Res. Pap. INT-272. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1981. 34 p.

Zimmermann, G. L. The wood and bark biomass and production of *Populus tremuloides*, *Abies lasiocarpa* and *Picea engelmannii* in northern Utah. Logan, UT: Utah State University; 1979. 84 p. M.S. thesis.

APPENDIX A

Program Listing for ASPEN

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? USER 950012001/SONJA
? CLASS 60
? COMPILE ASPEN FORTRAN LIBRARY
? DATA
 $ RESET FREE
FILE  5(KIND=READER)
FILE  6(KIND=PRINTER)
C.....    PROGRAM ASPEN
C.....THIS FORTRAN PROGRAM WAS REVISED FROM AN EARLIER SIMCOMP
C.....3.0 VERSION WHICH WAS RUN AT CSU.  IT WAS INITIALLY
C.....WRITTEN BY BARTOS AND JAMESON IN 1972 AND REVISED IN
C.....JANUARY 1977 BY BARTOS WITH THE AID OF INNIS TO RUN
C.....ON THE BURROUGHS SYSTEM AT USU.
C.....SUBSTANTIAL MODIFICATIONS WERE MADE IN 1980-81 BY BARTOS
C.....AND WARD.
C.....
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C.....
C.....
C.....        THE FOLLOWING DATA CARDS ARE NEEDED TO RUN THIS PROGRAM.
C.....        ALL ARE DONE IN FREE FORMAT.
C.....
C.....     1 = DT, TEND, STEP, PSTSZ
C.....  2-29 = VARIOUS PARAMETERS (5 PER CARD)
C.....
C.....
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C.....
C.....
C.....        LIST OF STATE VARIABLES
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C.....              ASP  = ASPEN BIOMASS      KG/HEC
C.....              CON  = CONIFER BIOMASS      KG/HEC
C.....              ANN  = ANNUAL BIOMASS      KG/HEC
C.....              PER  = PERENNIAL BIOMASS      KG/HEC
C.....              SHU  = SHRUB BIOMASS     KG/HEC
C.....            BIOSOR = BIOMASS LEFT IN SOURCE     KG/HEC
C.....            BIOSIN = BIOMASS GONE TO SINK         KG/HEC
C.....              ASP1 = ASPEN SUCKERS LESS THAN .5 M TALL      #/HEC
C.....              ASP2 = ASPEN SUCKERS .5 M - 2 M TALL       #/HEC
C.....              ASP3 = ASPEN SUCKERS OVER 2 M TALL BUT
C.....                     LESS THAN 5.08 CM DBH                #/HEC
C.....            SUCSOR = ASPEN SUCKERS LEFT IN SOURCE  #/HEC
C.....            SUCSIN = ASPEN SUCKERS GONE TO SINK    #/HEC
C.....              CON1 = CONIFER SEEDLINGS LESS THAN .5 M TALL      #/HEC
C.....              CON2 = CONIFER SEEDLINGS .5 M TO 2 M TALL     #/HEC
C.....              CON3 = CONIFER SEEDLINGS OVER 2 M TALL BUT
C.....                     LESS THAN 5.08 CM DBH                #/HEC
C.....            SEESOR = CONIFER SEEDLINGS LEFT IN SOURCE  #/HEC
C.....            SEESIN = CONIFER SEEDLINGS GONE TO SINK    #/HEC
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C.....
C.....
C.....         LIST OF AUXILIARY VARIABLES
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C.....             NOCON = NUMBER TREES IN CON     #/HEC
C.....              AWPC = AVERAGE MASS OF CONIFERS   KG/TREE
C.....                     CON/NOCON   OR -1 IF NOCON=0
C.....              HERB = PERENNIALS + ANNUALS      KG/HEC
C.....              ASPS = MASS OF ASPEN SUCKERS     KG/HEC
C.....              SHUH = MASS OF SHRUBS & ASPEN SUCKERS     KG/HEC
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C.....            SUC = TOTAL ASPEN SUCKERS      #/HEC
C.....           SEED = TOTAL CONIFER SEEDLINGS  #/HEC
C.....           CONN = MASS OF CONIFER SEEDLINGS   KG/HEC
C.....         BIOSUM = SUM OF BIOMASS STATE VARIABLES
C.....                    (SHOULD BE ZERO)      KG/HEC
C.....         SUCSUM = SUM OF ASPEN SUCKER STATE VARIABLES
C.....                    (SHOULD BE ZERO)      #/HEC
C.....         SEESUM = SUM OF CONIFER SEEDLING STATE VARIABLES
C.....                    (SHOULD BE ZERO)      #/HEC
C.....       AN M PRECEDING THE VARIABLE NAME REPRESENTS
C.....         THE MAXIMUM POSSIBLE VALUE OF THAT VARIABLE.
C.....
C.....       A P PRECEDING THE VARIABLE NAME REPRESENTS THE
C.....         PROPORTION THAT VARIABLE IS OF ITS MAXIMUM
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C.....
C.....
C.....         LIST OF TIME VARIABLES
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C.....           TIME = ELAPSED TIME            YEARS
C.....             DT = COMPUTATION STEPSIZE    YEARS
C.....           TEND = TIME AT WHICH RUN ENDS  YEARS
C.....           TTPR = TIME OF PRINTOUT        YEARS
C.....           STEP = TIME BETWEEN PRINTOUTS  YEARS
C.....           TTPL = TIME OF PLOT POINT      YEARS
C.....          PSTSZ = TIME BETWEEN PLOT POINTS YEARS
C.....           INDX = NUMBER OF STORED VALUE FOR PLOT
C.....        T(INDX) = TIME OF STORED VALUE FOR PLOT     YEARS
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C.....
      REAL NOCON,MHERB,MASP,MCON,MSHU,MCON1,MCON2,MCON3
      REAL MASP1,MASP2,MASP3,MCONN,MASPS,MSHUH,MANN,MPER
      DIMENSION P(140),T(101),Y1(2,101),Y2(2,101),Y3(2,101)
      DIMENSION Y4(3,101),Y5(3,101)
C.....
C.....     READ IN AND WRITE OUT TIME INFORMATION
C.....
      READ(5,/) DT,TEND,STEP,PSTSZ
      WRITE(6,31)DT,TEND,STEP,PSTSZ
   31 FORMAT(1H0,' DT = ',F5.1,5X,' TEND = ',F5.1,5X,' STEP = ',F5.1,
    /5X,'PSTSZ = ',I3)
C.....
C.....     READ IN AND WRITE OUT PARAMETERS FOR FLOW EQUATIONS
C.....
      DO 1114 M=1,140,5
 1114 READ(5,/)(P(M+MM),MM=0,4)
      WRITE(6,1005)
 1005 FORMAT('0')
      DO 1010 I = 1,140,5
      WRITE(6,1020)I,P(I),I+1,P(I+1),I+2,P(I+2),I+3,P(I+3),I+4,P(I+4)
 1010 CONTINUE
 1020 FORMAT(' ',5(2X,'P('I3') = 'F13.6))
C.....
C.....     ASSIGN AND WRITE OUT MAXIMUM VALUES OF STATE VARIABLES
C.....
      MASP = P(1)
      MCON = P(2)
      MSHU = P(3)
      MPER = P(4)
      MANN = P(5)
      MASP1 = P(6)
      MASP2 = P(7)
      MASP3 = P(8)
      MCON1 = P(9)
      MCON2 = P(10)
      MCON3 = P(11)
      MASPS = P(12)
      MSHUH = P(13)
      MCONN = P(14)
      MHERB = MANN + MPER
      WRITE(6,32)MASP,MCON,MHERB,MSHU,MCONN,MSHUH
   32 FORMAT(1H0,' MASP =',F10.2,2X,' MCON =',F10.2,2X,
     /'MHERB =',F10.2,2X,' MSHU =',F10.2,2X,'MCONN =',F10.2,
     /2X,'MSHUH =',F10.2)
      WRITE(6,33)MASP1,MASP2,MASP3,MCON1,MCON2,MCON3
   33 FORMAT(1H ,'MASP1 =',F10.2,2X,'MASP2 ='F10.2,2X,'MASP3 =',
     /F10.2,2X,'MCON1 ='F10.2,2X,'MCON2 =',F10.2,2X,'MCON3 =',F10.2)
      WRITE(6,34)MASPS,MPER,MANN
   34 FORMAT(1H ,'MASPS =',F10.2,2X,' MPER =',F10.2,2X,' MANN =',F10.2)
C.....
C.....      SET TIME AND COUNT TO 0.0
C.....
      TIME = 0.0
      TTPR = 0.0
      TTPL = 0.0
C.....
C.....      ASSIGN THE INITIAL VALUES OF THE STATE VARIABLES
C.....
      ASP = P(15)
      CON = P(16)
      SHU = P(17)
      PER = P(18)
      ANN = P(19)
      ASP1 = P(20)
      ASP2 = P(21)
      ASP3 = P(22)
      CON1 = P(23)
      CON2 = P(24)
      CON3 = P(25)
      NOCON = P(26)
C.....
C.....      UPDATE CORRESPONDING VALUES OF OTHER VARIABLES
C.....
      HERB = ANN + PER
      SUC  = ASP1+ASP2+ASP3
      SEED = CON1+CON2+CON3
      ASPS = P(27)*ASP1 + P(28)*ASP2 + P(29)*ASP3
      SHUH = SHU + ASPS
      CONN = P(30)*CON1 + P(31)*CON2 + P(32)*CON3
      BIOSOR = -ASP - CON - ANN - PER - SHU
      BIOSIN = 0.0
      SUCSOR = -ASP1 - ASP2 - ASP3
      SUCSIN = 0.0
      SEESOR = -CON1 - CON2 - CON3
      SEESIN = 0.0
      BIOSUM = BIOSOR + ASP + CON + ANN + PER + SHU + BIOSIN
      SUCSUM = SUCSOR + ASP1 + ASP2 + ASP3 + SUCSIN
      SEESUM = SEESOR + CON1 + CON2 + CON3 + SEESIN
      IF (NOCON.GT.0.0) GO TO 77
      AWPC = -1
      GO TO 78
   77 AWPC = CON/NOCON
   78 CONTINUE
C.....
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C.....
C.....
C.....      MAIN LOOP OF PROGRAM STARTS  HERE
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C.....
C.....      CHECK IF TIME TO STORE VALUES FOR PLOT
C.....
  250 IF(TIME.LT.TTPL) GO TO 35
      INDX = TIME/PSTSZ + 1
      T(INDX) = TIME
      Y1(1,INDX) = ASP
      Y1(2,INDX) = CON
      Y2(1,INDX) = ANN
      Y2(2,INDX) = PER
      Y3(1,INDX) = HERB
      Y3(2,INDX) = SHU
      Y4(1,INDX) = ASP1
      Y4(2,INDX) = ASP2
      Y4(3,INDX) = ASP3
      Y5(1,INDX) = CON1
      Y5(2,INDX) = CON2
      Y5(3,INDX) = CON3
C.....
C.....      UPDATE TTPL FOR NEXT PLOT TIME
C.....
      TTPL = TTPL + PSTSZ
C.....
C.....      CHECK IF TIME TO PRINT
C.....
   35 IF (TIME.LT.TTPR)GO TO 300
C.....
C.....      WRITE OUT VARIOUS VARIABLES AND TIME
C.....
      WRITE(6,500)TIME
  500 FORMAT(1H0,10X,'TIME',F7.2)
      WRITE(6,501)ASP,CON,SHU
  501 FORMAT(1H0,'    ASP =',F20.6,5X,'    CON =',F20.6,5X,
     /'    SHU =',F20.6)
      WRITE(6,502)ANN,PER,HERB
  502 FORMAT(1H ,'    ANN =',F20.6,5X,'    PER =',F20.6,5X,
     /'   HERB ='F20.6)
      WRITE(6,507)ASP1,ASP2,ASP3
  507 FORMAT(1H ,'   ASP1 ='F20.6,5X,'   ASP2 =',F20.6,5X,
     /'   ASP3 =',F20.6)
      WRITE(6,508)CON1,CON2,CON3
  508 FORMAT(1H ,'   CON1 =',F20.6,5X,'   CON2 =',F20.6,5X,
     /'   CON3 =',F20.6)
      WRITE(6,509)NOCON,SUC,SEED
  509 FORMAT(1H ,' NOCON ='F20.6,5X,'    SUC =',F20.6,5X,
     /'   SEED =',F20.6)
      WRITE(6,510)BIOSUM,SUCSUM,SEESUM
  510 FORMAT(1H ,'BIOSUM ='F20.6,5X,'SUCSUM =',F20.6,5X,
     /'SEESUM =',F20.6)
      WRITE(6,511)AWPC
  511 FORMAT(1H ,'   AWPC =',F20.6)
C.....
C.....      UPDATE TTPR FOR NEXT PRINT TIME
C.....
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```
      TTPR = TTPR + STEP
C...
C.....      CHECK IF TIME TO STOP RUN
C.....
  300 IF(TEND.LE.TIME) GO TO 45
C.....
C.....      CALCULATE PROPORTIONS TO PUT ON A RELATIVE BASIS.
      PSHUH = SHUH/MSHUH
      IF(PSHUH.GT.1.)PSHUH = 1.
      PASPS = ASPS/MASPS
      IF(PASPS.GT.1.)PASPS=1.
      PHERB = HERB/MHERB
      IF(PHERB.GT.1.)PHERB=1.
      PASP = ASP/MASP
      IF(PASP.GT.1.)PASP=1.
      PCON = CON/MCON
      IF(PCON.GT.1.)PCON=1.
      PSHU = SHU/MSHU
      IF(PSHU.GT.1.)PSHU=1.
      PASP1 = ASP1/MASP1
      IF(PASP1.GT.1.)PASP1=1.
      PASP2 = ASP2/MASP2
      IF(PASP2.GT.1.)PASP2=1.
      PASP3 = ASP3/MASP3
      IF(PASP3.GT.1.)PASP3=1.
      PCON1 = CON1/MCON1
      IF(PCON1.GT.1.)PCON1=1.
      PCON2 = CON2/MCON2
      IF(PCON2.GT.1.)PCON2=1.
      PCON3 = CON3/MCON3
      IF(PCON3.GT.1.)PCON3=1.
      PCONN = CONN/MCONN
      IF (PCONN.GT.1.)PCONN=1.
      PPER = PER/MPER
      IF(PPER.GT.1.)PPER=1.
      PANN = ANN/MANN
      IF(PANN.GT.1.)PANN=1.
C.....       CALCULATE THE VARIOUS FLOWS
C.....
C.....       COMPUTE FLOW 14     ASP1 REGENERATION
C.....       AFFECTED BY ASP, CON, SHU, ASP1, ASP2, ASP3, CONN
C.....
      Z1=EXP(-P(33)*PASP)
      Z2=EXP(-P(34)*PCON)
      Z3=1.+(P(35)-1.)*PSHU
      Z4=1.+(P(36)-1.)*PASP1
      Z5=1.+(P(37)-1.)*PASP2
      Z6=1.+(P(38)-1.)*PASP3
      Z7=EXP(-P(39)*PCONN)
      FLOW14 = P(40)*Z1*Z2*Z3*Z4*Z5*Z6*Z7
C.....
C.....      COMPUTE FLOW 15      ASP1 MORTALITY
C.....      AFFECTED BY ASP1
C.....
      FLOW15 = ASP1*P(41)
C.....
C.....       COMPUTE FLOW16    ASP1 GRADUATION
C.....       AFFECTED BY ASP,CON,SHU,ASP1,ASP2,ASP3,CONN,HERB
C.....
      Z1=P(42)+(1.-P(42))*EXP(-P(43)*PASP)
      Z2=EXP(-P(44)*PCON)
      Z3=1.+(P(45)-1.)*PSHU
      Z4=1.+(P(46)-1.)*PASP2
      Z5=1.+(P(47)-1.)*PASP3**P(48)
      Z6=EXP(-P(49)*PCONN)
      Z7=1.+(P(50)-1.)*PHERB
      FLOW16 = ASP1*P(51)*Z1*Z2*Z3*Z4*Z5*Z6*Z7
C.....
C.....        COMPUTE FLOW17    ASP2 MORTALITY
C.....        AFFECTED BY ASP2
C.....
      FLOW17 = ASP2*P(52)
C......
C.....        COMPUTE FLOW18    ASP2 GRADUATION
C.....        AFFECTED BY ASP, CON, SHU, ASP2, ASP3, CONN
C.....
      Z1=P(53)+(1.-P(53))*EXP(-P(54)*PASP)
      Z2=EXP(-P(55)*PCON)
      Z3=1.+(P(56)-1.)*PSHU
      Z4=1.+(P(57)-1.)*PASP3
      Z5=EXP(-P(58)*PCONN)
      FLOW18 = ASP2*P(59)*Z1*Z2*Z3*Z4*Z5
C.....
C.....        COMPUTE FLOW19     ASP3 MORTALITY
C.....        AFFECTED BY ASP3
C.....
      FLOW19 = ASP3*P(60)
C.....
C.....        COMPUTE FLOW20     ASP3 GRADUATION
C.....        AFFECTED BY ASP, CON, SHU, ASP3
C.....
      Z1=P(61)+(1.-P(61))*EXP(-P(62)*PASP)
      Z2=EXP(-P(63)*PCON)
      Z3=1.+(P(64)-1.)*PSHU
      FLOW20 = ASP3*P(65)*Z1*Z2*Z3
C.....
C.....        COMPUTE FLOW1    ASP3 GRADUATION CONVERSION
C.....                         (ASP GENERATION)
C.....
      FLOW1 = FLOW20*P(66)
C.....
C.....        COMPUTE FLOW2     ASP GROWTH
C.....        AFFECTED BY ASP, CON
C.....
      Z1=1.-(1.-P(67)*.99/P(68))*PASP
      Z2=1.+(P(69)-1.)*PCON**P(70)
      FLOW2 = ASP*P(68)*Z1*Z2
C.....
C.....        COMPUTE FLOW3     ASP MORTALITY
C.....        AFFECTED BY ASP
C.....
      FLOW3 = ASP*P(67)
C.....
C.....        COMMPUTE FLOW21     CON1 REGENERATION
C.....        AFFECTED BY ASP, CON, CON2, CON3, SHUH,HERB
C.....
      Z1=P(71)+(1.-P(71))/P(72)*PASP
      IF (Z1.GT.1.) Z1=1.
      Z2=1.+(P(73)-1.)*PCON**P(74)
      Z3=1.+(P(75)-1.)*PCON2
      Z4=1.+(P(76)-1.)*PCON3
      Z5=1.+(P(77)-1.)*PSHUH
      Z6=1.+(P(78)-1.)*PHERB
      FLOW21 = P(79)*Z1*Z2*Z3*Z4*Z5*Z6
C.....
C.....       P(80) YEAR TIME DELAY IN CONIFER REPRODUCTION
C.....
      IF (TIME.LE.P(80)) FLOW21=0.
C.....
C.....         COMPUTE FLOW22      CON1 MORTALITY
C.....         AFFECTED BY CON1
C.....
      FLOW22 = CON1*P(81)
C.....
C.....         COMPUTE FLOW23      CON1 GRADUATION
C.....         AFFECTED BY ASP, CON,CON1,CON2,CON3,SHUH,HERB
C.....
      Z1=1.+(P(82)-1.)*PASP
      Z2=1.+(P(83)-1.)*PCON
      Z3=1.+(P(84)-1.)*PCON2**P(85)
      Z4=1.+(P(86)-1.)*PCON3
      Z5=1.+(P(87)-1.)*PSHUH
      Z6=1.+(P(88)-1.)*PHERB
      FLOW23 = CON1*P(89)*Z1*Z2*Z3*Z4*Z5*Z6
C.....
C.....        COMPUTE FLOW24      CON2 MORTALITY
C.....        AFFECTED BY CON2
C.....
      FLOW24 = CON2*P(90)
C.....
C.....         COMPUTE FLOW25    CON2 GRADUATION
C.....         AFFECTED BY ASP,CON,CON2,CON3,
C.....
      Z1=1.+(P(91)-1.)*PASP
      Z2=1.+(P(92)-1.)*PCON
      Z3=1.+(P(93)-1.)*PCON2**P(94)
      Z4=1.+(P(95)-1.)*PCON3**P(96)
      FLOW25 = CON2*P(97)*Z1*Z2*Z3*Z4
C.....
C.....         COMPUTE FLOW26      CON3 MORTALITY
C.....         AFFECTED BY CON3
C.....
      FLOW26 = CON3*P(98)
C.....
C.....         COMPUTE FLOW27      CON3 GRADUATION (NOCON GENERATION)
C.....         AFFECTED BY ASP, CON, CON3
C.....
      Z1=1.+(P(99)-1.)*PASP
      Z2=1.+(P(100)-1.)*PCON
      FLOW27 = CON3*P(101)*Z1*Z2
C.....
C.....        COMPUTE FLOW4       CON3 GRADUATION CONVERSION
C.....                            (CON GENERATION)
C.....
      FLOW4 = FLOW27*P(102)
C.....
C.....        COMPUTE FLOW5       CON GROWTH
C.....        AFFECTED BY ASP, CON
C.....
      Z1=P(103)+(1.-P(103))*EXP(-P(104)*PASP)
      Z2=1.-(1.-P(105)*.99/P(106))*PCON
      FLOW5 = CON*P(106)*Z1*Z2
C.....
```

```
C.....      COMPUTE FLOW30       NOCON MORTALITY
C.....     AFFECTED BY  NOCON
C.....
      FLOW30 = NOCON*P(105)
C.....
C.....      COMPUTE FLOW6      CON MORTALITY
C.....     AFFECTED BY CON
C.....
      FLOW6 = CON*P(105)
C.....
C.....      COMPUTE FLOW7      ANN PRODUCTION
C.....     AFFECTED BY ASP, CON, PER, SHUH,CONN
C.....
      Z1 = EXP(-P(107)*PASP)
      Z2 = P(108)+(1.-P(108))*EXP(-P(109)*PCON)
      Z3 = 1.+(P(110)-1.)*PPER
      Z4 = EXP(-P(111)*PSHUH)
      Z5 = P(112)+(1.-P(112))*EXP(-P(113)*PCONN)
      FLOW7 = P(114)*Z1*Z2*Z3*Z4*Z5
C.....
C.....     ANNUAL MORTALITY ASSUMED TO BE 100% EACH YEAR
C.....
      FLOW8 = ANN/DT
C.....
C.....     COMPUTE FLOW9      PER PRODUCTION
C.....     AFFECTED BY ASP, CON, ANN, SHUH, CONN
C.....
      Z1 = 1.+(P(115)-1.)*PASP
      Z2 = P(116)+(1.-P(116))*EXP(-P(117)*PCON)
      Z3 = 1.+(P(118)-1.)*PANN
      Z4 = 1.+(P(119)-1.)*PSHUH
      Z5 = P(120)+(1.-P(120))*EXP(-P(121)*PCONN)
      FLOW9 = P(122)*Z1*Z2*Z3*Z4*Z5
C.....
C.....     PER MORTALITY (ABOVE GROUND) ASSUMED TO BE 100% EACH YEAR
C.....
      FLOW10 = PER/DT
C.....
C.....     COMPUTE FLOW11      SHU REGENERATION
C.....     AFFECTED BY ASP,CON,SHU, ASPS, CONN,HERB
C.....
      Z1=EXP(-P(123)*PASP)
      Z2=EXP(-P(124)*PCON)
      Z3 = 1.+(P(125)-1.)*PSHU**P(126)
      Z4 = 1.+(P(127)-1.)*PASPS
      Z5 = EXP(-P(128)*PCONN)
      Z6 = 1.+(P(129)-1.)*PHERB
      FLOW11 = P(130)*Z1*Z2*Z3*Z4*Z5*Z6
C.....
C.....     COMPUTE FLOW12      SHU GROWTH
C.....     AFFECTED BY ASP, CON, SHU, ASPS, CONN, HERB
C.....
      Z1 = 1.+(P(131)-1.)*PASP
      Z2 = 1.+(P(132)-1.)*PCON**P(133)
      Z3 = 1.-(1.-P(134)*.99/P(135))*PSHU
      Z4 = 1.+(P(136)-1.)*PASPS
      Z5 = 1.+(P(137)-1.)*PCONN
      Z6 = 1.+(P(138)-1.)*PHERB
      FLOW12 = SHU*P(135)*Z1*Z2*Z3*Z4*Z5*Z6
C.....
C.....     COMPUTE FLOW13      SHU MORTALITY
```

```
C.....      AFFECTED BY SHU
C.....
      FLOW13 = SHU*P(134)
C.....
C.....      UPDATE STATE VARIABLES
C.....
      ASP = ASP + DT * (FLOW1 + FLOW2 - FLOW3)
      CON = CON + DT * (FLOW4 + FLOW5 - FLOW6)
      ANN = ANN + DT * (FLOW7 - FLOW8)
      PER = PER + DT * (FLOW9 - FLOW10)
      SHU = SHU + DT * (FLOW11 + FLOW12 - FLOW13)
      BIOSOR = BIOSOR + DT * (-FLOW1-FLOW2-FLOW4-FLOW5-
     1FLOW7-FLOW9-FLOW11-FLOW12)
      BIOSIN = BIOSIN + DT * (FLOW3+FLOW6+FLOW8+FLOW10+FLOW13)
      ASP1 = ASP1 + DT * (FLOW14 - FLOW15 - FLOW16)
      ASP2 = ASP2 + DT * (FLOW16 - FLOW17 - FLOW18)
      ASP3 = ASP3 + DT * (FLOW18 - FLOW19 - FLOW20)
      SUCSOR = SUCSOR + DT * (-FLOW14)
      SUCSIN = SUCSIN + DT * (FLOW15+FLOW17+FLOW19+FLOW20)
      CON1 = CON1 + DT * (FLOW21 - FLOW22 - FLOW23)
      CON2 = CON2 + DT * (FLOW23 - FLOW24 - FLOW25)
      CON3 = CON3 + DT * (FLOW25 - FLOW26 - FLOW27)
      SEESOR = SEESOR + DT * (-FLOW21)
      SEESIN = SEESIN + DT * (FLOW22+FLOW24+FLOW26+FLOW27)
C.....
C.....         UPDATE VARIOUS AUXILIARY VARIABLES
C.....
      HERB = ANN + PER
      ASPS = P(27)*ASP1 + P(28)*ASP2 + P(29)*ASP3
      SHUH = SHU + ASPS
      CONN = P(30)*CON1 + P(31)*CON2 + P(32)*CON3
      NOCON = NOCON + DT * (FLOW27 -FLOW30)
      SUC = ASP1 + ASP2 + ASP3
      SEED = CON1 + CON2 + CON3
      BIOSUM = BIOSOR + ASP + CON + ANN + PER + SHU + BIOSIN
      SUCSUM = SUCSOR + ASP1 + ASP2 + ASP3 + SUCSIN
      SEESUM = SEESOR + CON1 + CON2 + CON3 + SEESIN
      IF(NOCON.GT.0.0) GO TO 240
      AWPC=-1.
      GO TO 242
  240 AWPC=CON/NOCON
  242 CONTINUE
C.....
C.....      UPDATE TIME
C.....
 249  TIME  = TIME  + DT
C.....
      GO TO 250
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C.....        MAIN LOOP OF PROGRAM ENDS HERE
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C.....
C.....         DRAW GRAPHS OF SELECTED STATE VARIABLES
C.....
   45 WRITE(6,512)
  512 FORMAT(1H1,30X,'1 = ASP      2 = CON',/)
      CALL PLOTS(2,INDX,T,Y1)
      WRITE(6,513)
  513 FORMAT(1H1,30X,'1 = ANN      2 = PER',/)
      CALL PLOTS(2,INDX,T,Y2)
      WRITE(6,514)
  514 FORMAT(1H1,30X,'1 = HERB      2 = SHU',/)                         00054600
      CALL PLOTS(2,INDX,T,Y3)                                           00054700
      WRITE(6,515)                                                      00054800
  515 FORMAT(1H1,30X,'1 = ASP1      2 = ASP2       3 = ASP3',/)         00054900
      CALL PLOTS(3,INDX,T,Y4)                                           00055000
      WRITE(6,516)                                                      00055100
  516 FORMAT(1H1,30X,'1 = CON1      2 = CON2       3 = CON3',/)         00055200
      CALL PLOTS(3,INDX,T,Y5)                                           00055300
       END                                                              00055400
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC00055500
C.....       END OF MAIN PROGRAM                                        00055600
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC00055700
C.....                                                                  00055800
C.....                                                                  00055900
C.....       GRAPHING SUBROUTINES                                       00056000
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC00056100
      SUBROUTINE PLOTS(NPLOTS,NPTS,X,Y)                                 00056200
      COMMON/IO/NI,NO                                                   00056300
      DIMENSION X(NPTS),Y(NPLOTS,NPTS),XSCL(101),YSCL(52),ILINE(101)    00056400
      NI = 5                                                            00056500
      NO = 6                                                            00056600
      XMIN=X(1)                                                         00056700
      XMAX=X(1)                                                         00056800
      DO 1 I=1,NPTS                                                     00056900
      IF(X(I).GT.XMAX)XMAX=X(I)                                         00057000
1     IF(X(I).LT.XMIN)XMIN=X(I)                                         00057100
      YMIN=Y(1,1)                                                       00057200
      YMAX=Y(1,1)                                                       00057300
      DO 2 I=1,NPLOTS                                                   00057400
      DO 2 J=1,NPTS                                                     00057500
      IF(Y(I,J).LT.YMIN)YMIN=Y(I,J)                                     00057600
2     IF(Y(I,J).GT.YMAX)YMAX=Y(I,J)                                     00057700
7     SCALX=(XMAX-XMIN)/100.                                            00057800
      SCALY=(YMAX-YMIN)/50.                                             00057900
      DO 3 I=1,101                                                      00058000
      XSCL(I)=XMIN+FLOAT(I-1)*SCALX                                     00058100
      IF(I.GT.52)GO TO 3                                                00058200
      YSCL(I)=YMAX-FLOAT(I-1)*SCALY                                     00058300
3     CONTINUE                                                          00058400
C.....                                                                  00058500
      CALL GZRO(0,ILINE)                                                00058600
C.....                                                                  00058700
      DO 5 K=1,51                                                       00058800
      CALL GZRO(K,ILINE)                                                00058900
      CALL SKPT(NPLOTS,NPTS,K,X,Y,YSCL,XMIN,SCALX,ILINE)                00059000
5     CALL TYPIT(K,YSCL,ILINE)                                          00059100
      CALL GZRO(0,ILINE)                                                00059200
      WRITE(NO,6)(XSCL(I),I=1,101,20)                                   0005930
6     FORMAT(17X,F7.2,5(13X,F7.2))                                      0005940
      RETURN                                                            0005950
      END                                                               0005960
C.....                                                                  0005970
      SUBROUTINE SKPT(NPLOTS,NPTS,K,X,Y,YSCL,XMIN,SCALX,ILINE)          0005980
C.....                                                                  0005990
      DIMENSION X(NPTS),Y(NPLOTS,NPTS),ILINE(1),YSCL(1),ISYM(11)        0006000
      DATA ISYM/1H1,1H2,1H3,1H4,1H5,1H6,1H7,1H8,1H9,1H0,1HC/            0006010
      DATA IBLK/1H /                                                    0006020
      DO 1 I=1,NPLOTS                                                   0006030
      DO 1 J=1,NPTS                                                     0006040
      IF(Y(I,J).GT.YSCL(K))GO TO 1                                      0006050
      IF(Y(I,J).LE.YSCL(K+1))GO TO 1                                    0006060
      M=INT((X(J)-XMIN)/SCALX+1.5)
      IF(M.LT.1)GO TO 1
      IF(M.GT.101)GO TO 1
      IF(ILINE(M).EQ.IBLK)GO TO 2
      ILINE(M)=ISYM(11)
      GO TO 1
2     ILINE(M)=ISYM(I)
1     CONTINUE
      RETURN
      END
C.....
      SUBROUTINE TYPIT(K,YSCL,ILINE)
C.....
      COMMON/IO/NI,NO
      DIMENSION YSCL(1),ILINE(1)
      JS=K+4
      IF((JS-JS/5*5).NE.0)GO TO 1
      WRITE(NO,6) YSCL(K)
    6 FORMAT(10X,E10.3,2H +)
      WRITE(NO,2)(ILINE(I),I=1,101)
2     FORMAT(1H+,20X,101A1,2X,2H+I)
      GO TO 3
    1 WRITE(NO,5)
    5 FORMAT(21X,1H-)
      WRITE(NO,4)(ILINE(I),I=1,101)
4     FORMAT(1H+,20X,101A1,2X,2H-I)
3     RETURN
      END
C.....
      SUBROUTINE GZRO(K,ILINE)
C.....
      COMMON/IO/NI,NO
      DIMENSION ILINE(1)
      DATA IPER,IN,IBLK/1H.,1H1,1H /
      IF(K.EQ.0)GO TO 2
      DO 1 I=1,101
1     ILINE(I)=IBLK
      RETURN
2     DO 3 I=1,101
3     ILINE(I)=IPER
      DO 4 I=1,101,10
4     ILINE(I)=IN
      WRITE(NO,5)(ILINE(I),I=1,101)
5     FORMAT(19X,2H..,101A1,2H..)
      RETURN
      END
```

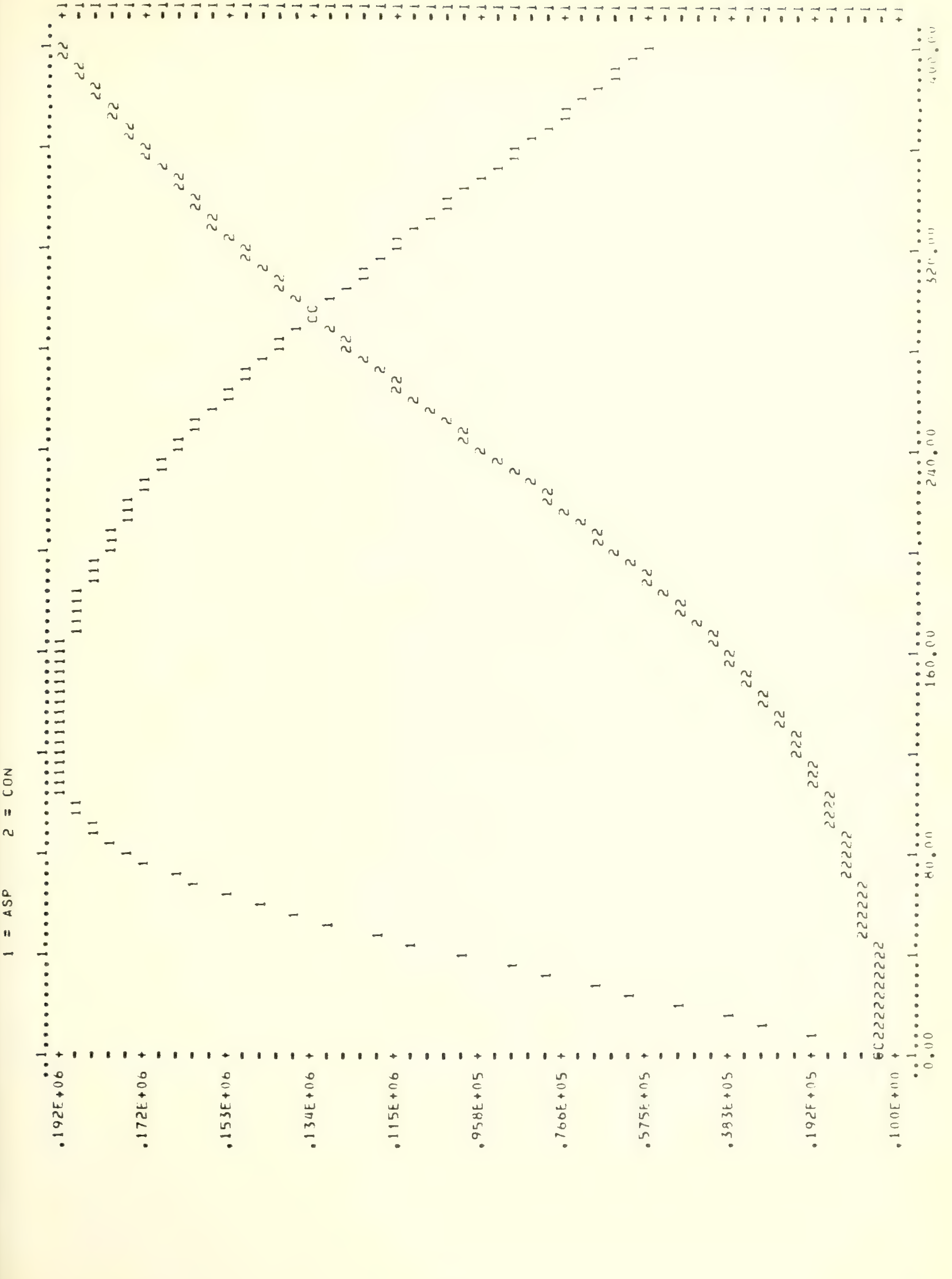
```
? DATA
1.,400.,100.,4.
200000.,250000.,10000.,3500.,500.
100000.,50000.,15000.,100000.,10000.
2500.,15000.,15000.,15000.,.1
.1,.1,.1,500.,.1
.1,.1,.1,.1,.1
0.,.006,.1,.8,.02
.4,2.4,5.,6.,.8
.3,.1,.001,6.,100000.
.45,.1,5.,5.,.5
.001,.001,.67,5.,.8
.25,.25,.1,5.,5.
.7,.001,5.,.2,.1
.1,5.,5.,.8,.15
4.,.03,.08,.001,1.2
.6,.25,.1,3.,.2
.2,.2,.001,1000.,5.
.7,.5,.3,.5,3.
.2,.7,.7,.3,.45
.5,.3,.7,3.,.5
3.,.25,.1,.5,.3
.2,6.,.5,3.,.02
.07,2.,.005,6.,.6
2.,.005,6.,500.,.5
.007,6.,.7,.5,.007
6.,3500.,4.,6.,.1
3.5,.4,6.,.8,100.
.5,.001,.5,.03,.2
.5,.01,.4,0,0
? END
```

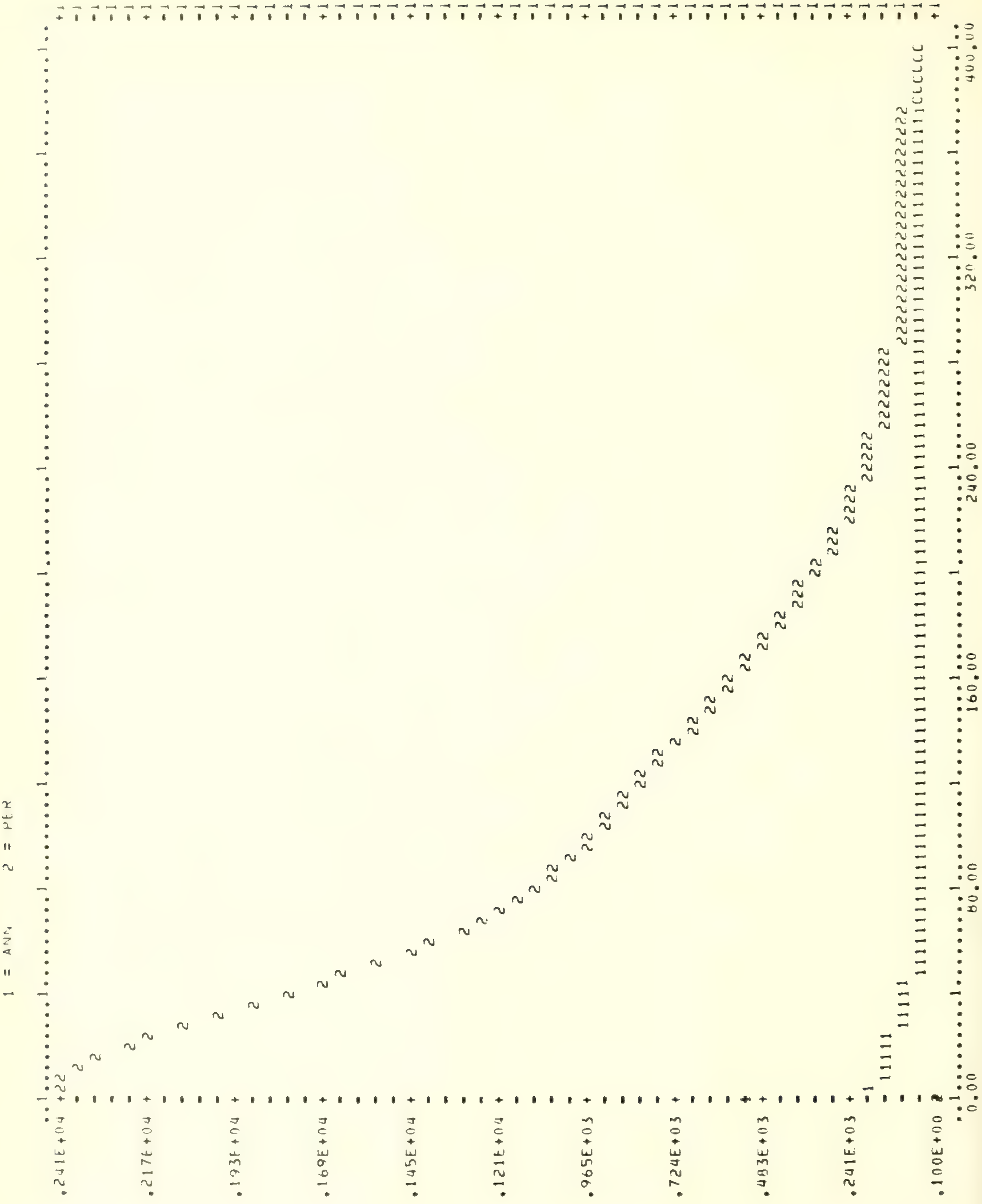
Sample Output from ASPEN Program

```
 DT =    1.0       TEND = 400.0       STEP = 100.0       PSTSZ =    4


  P(  1) = 200000.000000  P(  2) = 250000.000000  P(  3) =  10000.000000  P(  4) =    3500.000000  P(  5) =     500.000000
  P(  6) = 100000.000000  P(  7) =  50000.000000  P(  8) =  15000.000000  P(  9) = 100000.000000  P( 10) =   10000.000000
  P( 11) =   2500.000000  P( 12) =  15000.000000  P( 13) =  15000.000000  P( 14) =  15000.000000  P( 15) =       0.100000
  P( 16) =      0.100000  P( 17) =      0.100000  P( 18) =      0.100000  P( 19) =     500.000000  P( 20) =       0.100000
  P( 21) =      0.100000  P( 22) =      0.100000  P( 23) =      0.100000  P( 24) =       0.100000  P( 25) =       0.100000
  P( 26) =      0.000000  P( 27) =      0.006000  P( 28) =      0.100000  P( 29) =       0.800000  P( 30) =       0.020000
  P( 31) =      0.400000  P( 32) =      2.400000  P( 33) =      5.000000  P( 34) =       6.000000  P( 35) =       0.800000
  P( 36) =      0.300000  P( 37) =      0.100000  P( 38) =      0.001000  P( 39) =       6.000000  P( 40) =  100000.000000
  P( 41) =      0.450000  P( 42) =      0.100000  P( 43) =      5.000000  P( 44) =       5.000000  P( 45) =       0.500000
  P( 46) =      0.001000  P( 47) =      0.001000  P( 48) =      0.670000  P( 49) =       5.000000  P( 50) =       0.800000
  P( 51) =      0.250000  P( 52) =      0.250000  P( 53) =      0.100000  P( 54) =       5.000000  P( 55) =       5.000000
  P( 56) =      0.700000  P( 57) =      0.001000  P( 58) =      5.000000  P( 59) =       0.200000  P( 60) =       0.100000
  P( 61) =      0.100000  P( 62) =      5.000000  P( 63) =      5.000000  P( 64) =       0.800000  P( 65) =       0.150000
  P( 66) =      4.000000  P( 67) =      0.030000  P( 68) =      0.080000  P( 69) =       0.001000  P( 70) =       1.200000
  P( 71) =      0.600000  P( 72) =      0.250000  P( 73) =      0.100000  P( 74) =       3.000000  P( 75) =       0.200000
  P( 76) =      0.200000  P( 77) =      0.200000  P( 78) =      0.001000  P( 79) =    1000.000000  P( 80) =       5.000000
  P( 81) =      0.700000  P( 82) =      0.500000  P( 83) =      0.300000  P( 84) =       0.500000  P( 85) =       3.000000
  P( 86) =      0.200000  P( 87) =      0.700000  P( 88) =      0.700000  P( 89) =       0.300000  P( 90) =       0.450000
  P( 91) =      0.500000  P( 92) =      0.300000  P( 93) =      0.700000  P( 94) =       3.000000  P( 95) =       0.500000
  P( 96) =      3.000000  P( 97) =      0.250000  P( 98) =      0.100000  P( 99) =       0.500000  P(100) =       0.300000
  P(101) =      0.200000  P(102) =      6.000000  P(103) =      0.500000  P(104) =       3.000000  P(105) =       0.020000
  P(106) =      0.070000  P(107) =      2.000000  P(108) =      0.005000  P(109) =       6.000000  P(110) =       0.600000
  P(111) =      2.000000  P(112) =      0.005000  P(113) =      6.000000  P(114) =     500.000000  P(115) =       0.500000
  P(116) =      0.007000  P(117) =      6.000000  P(118) =      0.700000  P(119) =       0.500000  P(120) =       0.007000
  P(121) =      6.000000  P(122) =   3500.000000  P(123) =      4.000000  P(124) =       6.000000  P(125) =       0.100000
  P(126) =      3.500000  P(127) =      0.400000  P(128) =      6.000000  P(129) =       0.800000  P(130) =     100.000000
  P(131) =      0.500000  P(132) =      0.001000  P(133) =      0.500000  P(134) =       0.030000  P(135) =       0.200000
  P(136) =      0.500000  P(137) =      0.010000  P(138) =      0.400000  P(139) =       0.000000  P(140) =       0.000000

 MASP = 200000.00   MCON = 250000.00  MHERB =    4000.00   MSHU =  10000.00  MCONN =  15000.00  MSHUH =  15000.00
MASP1 = 100000.00  MASP2 =  50000.00  MASP3 =   15000.00  MCON1 = 100000.00  MCON2 =  10000.00  MCON3 =   2500.00
MASPS =  15000.00   MPER =   3500.00   MANN =     500.00

           TIME    0.00

     ASP =            0.100000        CON =           0.100000         SHU =           0.100000
     ANN =          500.000000        PER =           0.100000        HERB =         500.100000
    ASP1 =            0.100000       ASP2 =           0.100000        ASP3 =           0.100000
    CON1 =            0.100000       CON2 =           0.100000        CON3 =           0.100000
   NOCON =            0.000000        SUC =           0.300000        SEED =           0.300000
  BIOSUM =           -0.000000     SUCSUM =          -0.000000      SEESUM =          -0.000000
    AWPC =           -1.000000
```

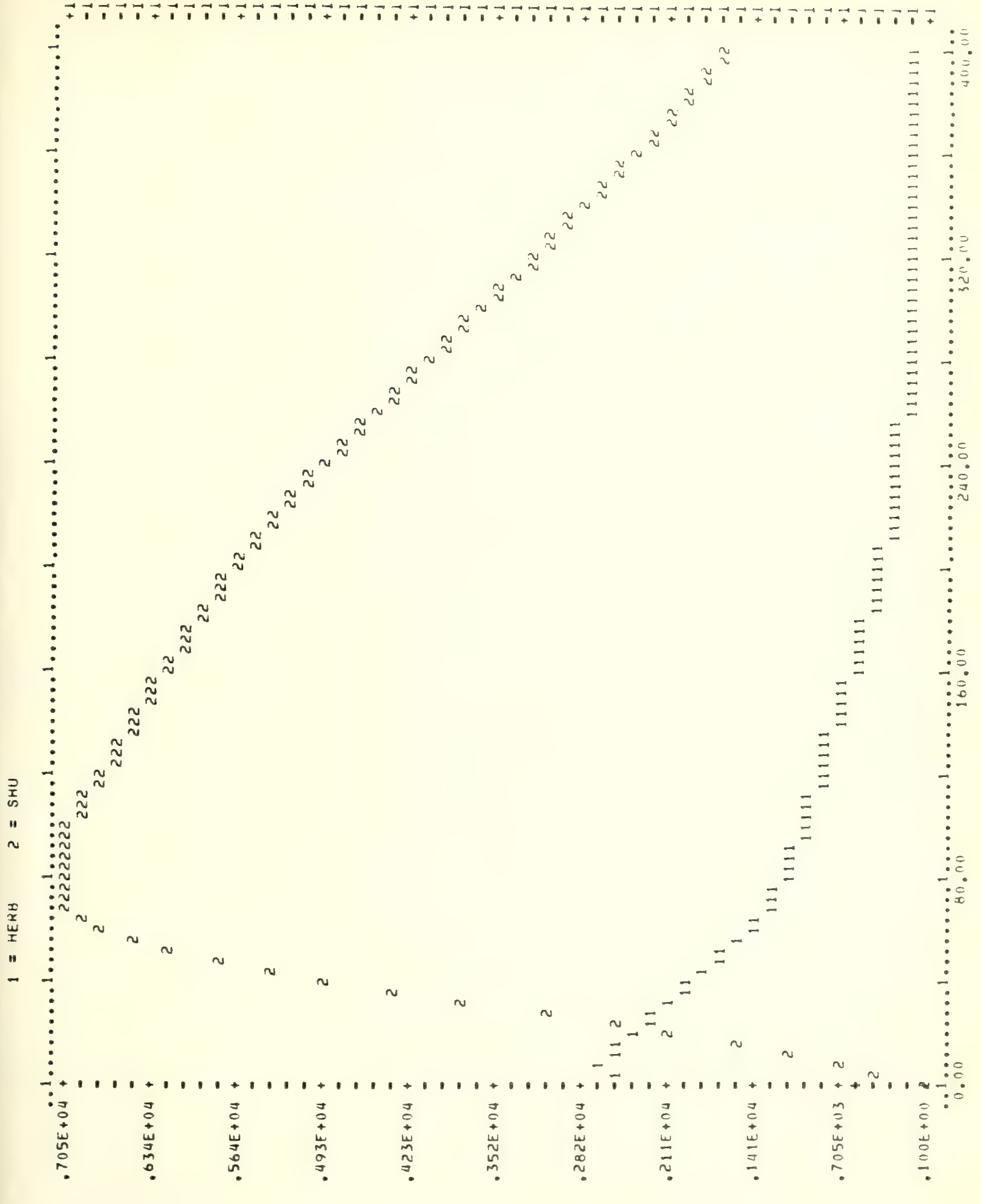
```
          TIME 100.00

     ASP =        186676.798394       CON =       13964.229435       SHU =        6919.736938
     ANN =            18.009987       PER =         934.533414      HERB =         952.543401
    ASP1 =          1172.351872      ASP2 =          57.372357      ASP3 =          10.187821
    CON1 =           563.676260      CON2 =         116.566561      CON3 =          73.493727
   NOCON =           384.043300       SUC =        1239.912050      SEED =         753.736548
  BIOSUM =            -0.000015    SUCSUM =           0.000000    SEESUM =           0.000000
    AWPC =            36.361081

          TIME 200.00

     ASP =        179628.487203       CON -       62396.969088       SHU =        5578.318924
     ANN =             7.780726       PER =         323.676584      HERB =         331.457309
    ASP1 =           443.274035      ASP2 =           9.618390      ASP3 =           0.627259
    CON1 =           746.153445      CON2 =         151.408757      CON3 =          89.396066
   NOCON =           391.575932       SUC =         453.519683      SEED =         986.958268
  BIOSUM =             0.000000    SUCSUM =           0.000000    SEESUM =           0.000003
    AWPC =           159.348326

          TIME 300.00

     ASP =        128042.435857       CON =      136588.431256       SHU =        3587.097254
     ANN =             3.226571       PER =          83.181603      HERB =          86.408175
    ASP1 =           277.830569      ASP2 =           1.860322      ASP3 =           0.032086
    CON1 =           796.257013      CON2 =         161.884557      CON3 =          92.714297
   NOCON =           399.206707       SUC =         279.722977      SEED =        1050.855867
  BIOSUM =             0.000019    SUCSUM =           0.000004    SEESUM =           0.000003
    AWPC =           342.149640

          TIME 400.00

     ASP =         56772.348892       CON =      191580.371622       SHU =        1565.700478
     ANN =             3.110401       PER =          43.975450      HERB =          47.085851
    ASP1 =           466.263862      ASP2 =           2.617593      ASP3 =           0.028442
    CON1 =           643.561039      CON2 =         132.709094      CON3 =          75.393348
   NOCON =           348.911140       SUC =         468.909897      SEED =         851.663481
  BIOSUM =            -0.000031    SUCSUM =           0.000000    SEESUM =           0.000003
    AWPC =           549.080697
```

APPENDIX B (cont.)

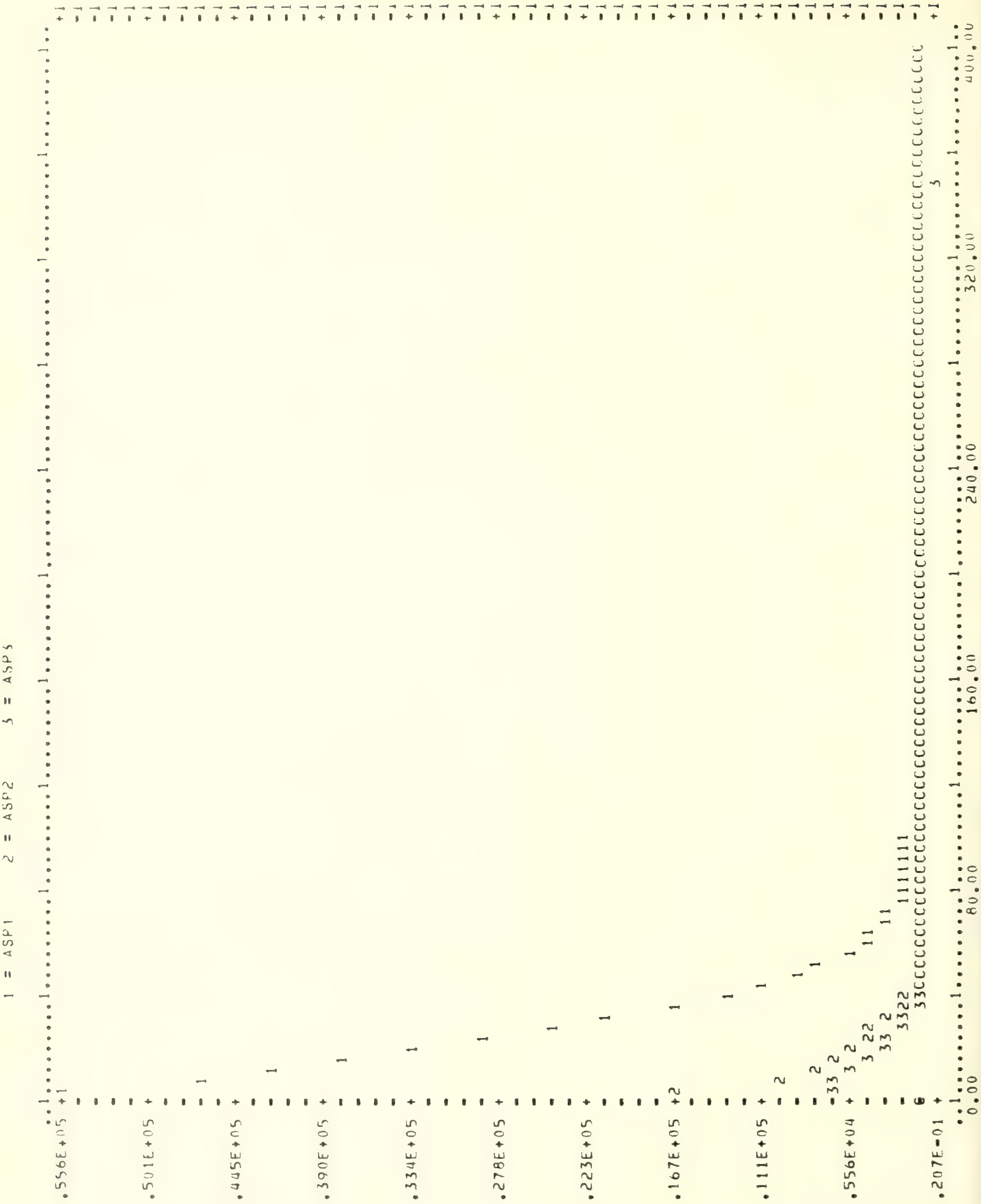



1 = ANN 2 = PER
.241E+04
.217E+04
.193E+04
.169E+04
.145E+04
.121E+04
.965E+03
.724E+03
.483E+03
.241E+03
.100E+00
0.00
80.00
160.00
240.00
320.00
400.00

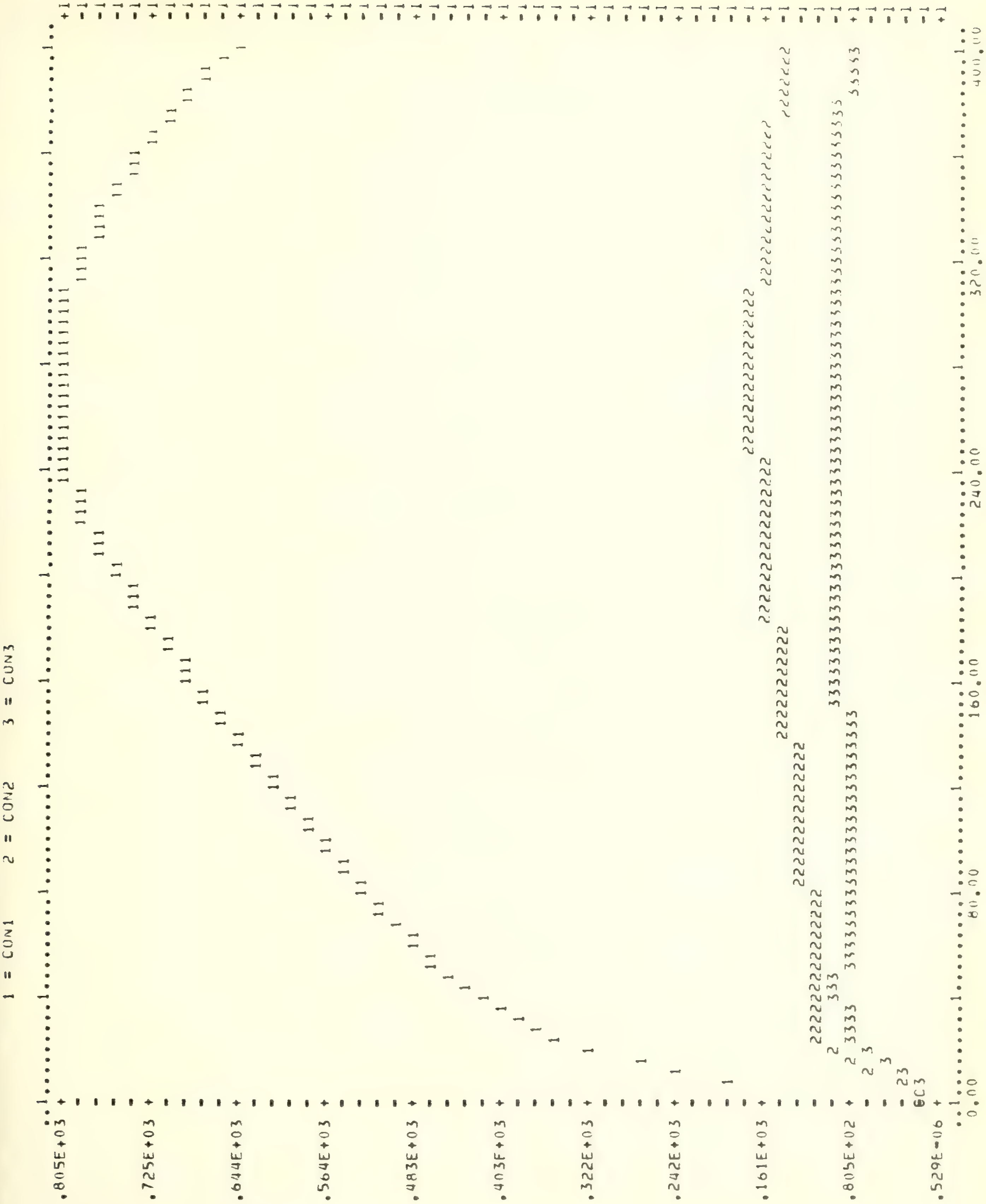
APPENDIX B (cont.)



APPENDIX B (cont.)



APPENDIX B (cont.)



APPENDIX C

Parameter Names, Definitions, Values, Range of Values, and Units for the ASPEN Program.

Parameter number	FORTRAN name	Definition	Value	Range	Units	Source
1	MASP	Maximum value for aspen biomass	200,000		kg/ha	Zimmermann 1979 Rodin and Bazilevich 1967
2	MCON	Maximum value for conifer biomass	250,000		kg/ha	Zimmermann 1979
3	MSHU	Maximum value for shrub biomass	10,000		kg/ha	Unpublished data (Bartos, files)
4	MPER	Maximum value for perennial biomass	3,500		kg/ha	Youngblood and Mueggler 1981
5	MANN	Maximum value for annual biomass	500		kg/ha	Youngblood and Mueggler 1981
6	MASP1	Maximum value for ASP1 reproduction class	100,000	80,000-120,000	Numbers/ha	Baker 1925 and unpublished data (Bartos, files)
7	MASP2	Maximum value for ASP2 reproduction class	50,000	40,000-60,000	Numbers/ha	Unpublished data (Bartos, files)
8	MASP3	Maximum value for ASP3 reproduction class	15,000	10,000-20,000	Numbers/ha	Mueggler and Bartos 1977
9	MCON1	Maximum value for CON1 reproduction class	100,000	80,000-120,000	Numbers/ha	Noble and Ronco 1978
10	MCON2	Maximum value for CON2 reproduction class	10,000	5,000-15,000	Numbers/ha	INT-1751 estimate
11	MCON3	Maximum value for CON3 reproduction class	2,500	1,000-5,000	Numbers/ha	INT-1751 estimate
12	MASPS	Maximum biomass value for the sum of all aspen suckers	15,000	10,000-20,000	kg/ha	INT-1751 estimate
13	MSHUH	Maximum biomass value for the sum of all aspen suckers and shrub biomass	15,000	10,000-20,000	kg/ha	INT-1751 estimate
14	MCONN	Maximum biomass value for the sum of all conifer seedlings	15,000	10,000-20,000	kg/ha	INT-1751 estimate
15	ASP	Initial value for state variable aspen	0.1	0-1.	kg/ha	— —
16	CON	Initial value for state variable conifer	.1	0-1.	kg/ha	— —
17	SHU	Initial value for state variable shrubs	.1	0-1.	kg/ha	— —
18	PER	Initial value for state variable perennials	.1	0-1.	kg/ha	— —

Parameter number	FORTRAN name	Definition	Value	Range	Units	Source
19	ANN	Initial value for state variable annuals	500	250-500	kg/ha	Bartos and Mueggler 1981
20	ASP1	Initial value for state variable ASP1	0.1	0-1.	Numbers/ha	— —
21	ASP2	Initial value for state variable ASP2	.1	0-1.	Numbers/ha	— —
22	ASP3	Initial value for state variable ASP3	.1	0-1.	Numbers/ha	— —
23	CON1	Initial value for state variable CON1	.1	0-1.	Numbers/ha	— —
24	CON2	Initial value for state variable CON2	.1	0-1.	Numbers/ha	— —
25	CON3	Initial value for state variable CON3	.1	0-1.	Numbers/ha	— —
26	NOCON	Initial value for conifer trees on site	0		Trees/ha	— —
27		Factor to convert sucker numbers (ASP1) to biomass	.006	.004-.006	kg/sucker	Bartos and Johnston 1978
28		Factor to convert sucker numbers (ASP2) to biomass	.1	.04-.11	kg/sucker	Bartos and Johnston 1978
29		Factor to convert sucker numbers (ASP3) to biomass	.8	.6-1.	kg/sucker	Bartos and Johnston 1978
30		Factor to convert seedling numbers (CON1) to biomass	.02	.01-.03	kg/seedling	Unpublished data (Bartos, files)
31		Factor to convert seedling numbers (CON2) to biomass	.4	.2-.6	kg/seedling	Unpublished data (Bartos, files)
32		Factor to convert seedling numbers (CON3) to biomass	2.4	2.-3.	kg/seedling	Unpublished data (Bartos, files)
33		Aspen restriction on ASP1 regeneration	5.	3.-7.	Dimensionless	INT-1751 Estimate
34		Conifer restriction on ASP1 regeneration	6.	4.-8.	Dimensionless	INT-1751 Estimate
35		Shrub restriction on ASP1 regeneration	0.8	.6-.9	Dimensionless	INT-1751 Estimate
36		ASP1 restriction on ASP1 regeneration	.3	.1-.5	Dimensionless	INT-1751 Estimate
37		ASP2 restriction on ASP1 regeneration	.1	0-.3	Dimensionless	INT-1751 Estimate

Parameter number	FORTRAN name	Definition	Value	Range	Units	Source
38		ASP3 restriction on ASP1 regeneration	.001	0-.2	Dimensionless	INT-1751 Estimate
39		CONN restriction on ASP1 regeneration	6.	4.-8.	Dimensionless	INT-1751 estimate
40		Unrestricted ASP1 regeneration rate	100,000	80,000-120,000	Suckers/ha/yr	Baker 1925 and unpublished data (Bartos, files)
41		ASP1 mortality	0.45	.3-.6	Yr^{-1}	Unpublished data (Bartos, files)
42		Aspen restriction on ASP1 graduation	.1	0-.2	Dimensionless	INT-1751 estimate
43		Aspen restriction on ASP1 graduation	5.	3.-7.	Dimensionless	INT-1751 estimate
44		Conifer restriction on ASP1 graduation	5.	3.-7.	Dimensionless	INT-1751 estimate
45		Shrub restriction on ASP1 graduation	.5	.3-.7	Dimensionless	INT-1751 estimate
46		ASP2 restriction on ASP1 graduation	.001	0-.2	Dimensionless	INT-1751 estimate
47		ASP3 restriction on ASP1 graduation	.001	0-.2	Dimensionless	INT-1751 estimate
48		ASP3 restriction on ASP1 graduation	.67	.33-1.	Dimensionless	INT-1751 estimate
49		CONN restriction on ASP1 graduation	5.	3.-7.	Dimensionless	INT-1751 estimate
50		Herb restriction on ASP1 graduation	.8	.7-.9	Dimensionless	INT-1751 estimate
51		Unrestricted ASP1 graduation rate	.25	.15-.35	Yr^{-1}	INT-1751 estimate
52		ASP2 mortality	.25	.15-.35	Yr^{-1}	Unpublished data (Bartos, files)
53		Aspen restriction on ASP2 graduation	.1	0-.2	Dimensionless	INT-1751 estimate
54		Aspen restriction on ASP2 graduation	5.	3.-7.	Dimensionless	INT-1751 estimate
55		Conifer restriction on ASP2 graduation	5.	3.-7.	Dimensionless	INT-1751 estimate
56		Shrub restriction on ASP2 graduation	.7	.5-.9	Dimensionless	INT-1751 estimate
57		ASP3 restriction on ASP2 graduation	.001	0-.2	Dimensionless	INT-1751 estimate

Parameter number	FORTRAN name	Definition	Value	Range	Units	Source
58		CONN restriction on ASP2 graduation	5.	3.-7.	Dimensionless	INT-1751 estimate
59		Unrestricted ASP2 graduation rate	.2	.1-.3	Yr^{-1}	INT-1751 estimate
60		ASP3 mortality	.1	.05-.15	Yr^{-1}	Unpublished data (Bartos, files)
61		Aspen restriction on ASP3 graduation	.1	0-.2	Dimensionless	INT-1751 estimate
62		Aspen restriction on ASP3 graduation	5.	3.-7.	Dimensionless	INT-1751 estimate
63		Conifer restriction on ASP3 graduation	5.	3.-7.	Dimensionless	INT-1751 estimate
64		Shrub restriction on ASP3 graduation	.8	.6-.9	Dimensionless	INT-1751 estimate
65		Unrestricted ASP3 graduation rate	.15	.1-.2	Yr^{-1}	INT-1751 estimate
66		ASP3 graduation conversion to biomass	4.	3.-5.	kg/tree	Bartos and Johnston 1978
67		Aspen mortality	.03	.02-.04	Yr^{-1}	INT-1751 estimate
68		Unrestricted aspen growth rate	.08	.06-1.	Yr^{-1}	INT-1751 estimate
69		Conifer restriction on aspen growth	.001	0-.02	Dimensionless	INT-1751 estimate
70		Conifer restriction on aspen growth	1.2	1.-1.4	Dimensionless	INT-1751 estimate
71		Aspen restriction on CON1 regeneration	.6	.4-.8	Dimensionless	INT-1751 estimate
72		Aspen restriction on CON1 regeneration	.25	.15-.35	Dimensionless	INT-1751 estimate
73		Conifer restriction on CON1 regeneration	.1	0-.2	Dimensionless	INT-1751 estimate
74		Conifer restriction on CON1 regeneration	3.	1.5-5.	Dimensionless	INT-1751 estimate
75		CON2 restriction on CON1 regeneration	.2	0-.4	Dimensionless	INT-1751 estimate
76		CON3 restriction on CON1 regeneration	.2	0-.4	Dimensionless	INT-1751 estimate
77		Shrub and aspen sucker restriction on CON1 regeneration	.2	0-.4	Dimensionless	INT-1751 estimate
78		Perennial and annual restriction on CON1 regeneration	.001	0-.2	Dimensionless	INT-1751 estimate

Parameter number	FORTRAN name	Definition	Value	Range	Units	Source
79		Unrestricted CON1 regeneration rate	1,000	750-1,250	Seedlings/ ha/yr	Noble and Ronco 1978
80		Time delay in years for conifer reproduction	5.	3.-10.	Yr	INT-1751 estimate
81		CON1 mortality	.7	.5-.9	Yr^{-1}	Noble and Ronco 1978
82		Aspen restriction on CON1 graduation	.5	.3-.7	Dimensionless	INT-1751 estimate
83		Conifer restriction on CON1 graduation	.3	.1-.5	Dimensionless	INT-1751 estimate
84		CON2 restriction on CON1 graduation	.5	.3-.7	Dimensionless	INT-1751 estimate
85		CON2 restriction on CON1 graduation	3.	1.-4.	Dimensionless	INT-1751 estimate
86		CON3 restriction on CON1 graduation	.2	0-.4	Dimensionless	INT-1751 estimate
87		Shrub and aspen sucker restriction on CON1 graduation	.7	.5-.9	Dimensionless	INT-1751 estimate
88		Perennial and annual restriction on CON1 graduation	.7	.5-.9	Dimensionless	INT-1751 estimate
89		Unrestricted CON1 graduation rate	.3	.1-.4	Yr^{-1}	INT-1751 estimate
90		CON2 mortality	.45	.3-.6	Yr^{-1}	Noble and Ronco 1978
91		Aspen restriction on CON2 graduation	.5	.3-.7	Dimensionless	INT-1751 estimate
92		Conifer restriction on CON2 graduation	.3	.1-.5	Dimensionless	INT-1751 estimate
93		CON2 restriction on CON2 graduation	.7	.5-.9	Dimensionless	INT-1751 estimate
94		CON2 restriction on CON2 graduation	3.	1.-4.	Dimensionless	INT-1751 estimate
95		CON3 restriction on CON2 graduation	.5	.3-.7	Dimensionless	INT-1751 estimate
96		CON3 restriction on CON2 graduation	3.	1.-4.	Dimension–less	INT-1751 estimate
97		Unrestricted CON2 graduation rate	.25	.2-.4	Yr^{-1}	INT-1751 estimate
98		CON3 mortality	.1	.05-.15	Yr^{-1}	Noble and Ronco 1978
99		Aspen restriction on CON3 graduation	.5	.3-.7	Dimensionless	INT-1751 estimate
100		Conifer restriction on CON3 graduation	.3	.1-.5	Dimensionless	INT-1751 estimate

Parameter number	FORTRAN name	Definition	Value	Range	Units	Source
101		Unrestricted CON3 graduation rate	.2	.1-.3	Yr^{-1}	INT-1751 estimate
102		CON3 graduation conversion to biomass	6.	5.-7.	Kg/tree	Long and Turner 1975
103		Aspen restriction on conifer growth	.5	.3-.7	Dimensionless	INT-1751 estimate
104		Aspen restriction on conifer growth	3.	2.-4.	Dimensionless	INT-1751 estimate
105		Conifer restriction on conifer growth, mortality of conifer trees (#'s) on site, and conifer biomass mortality	.02	.01-.03	Yr^{-1}	INT-1751 estimate
106		Conifer restriction on conifer growth and unrestricted conifer growth rate	.07	.05-.09	Yr^{-1}	INT-1751 estimate
107		Aspen restriction on production of annuals	2.	1.-3.	Dimensionless	INT-1751 estimate
108		Conifer restriction on production of annuals	.005	.001-.01	Dimensionless	INT-1751 estimate
109		Conifer restriction on production of annuals	6.	4.-8.	Dimensionless	INT-1751 estimate
110		Perennial restriction on production of annuals	.6	.4-.8	Dimensionless	INT-1751 estimate
111		Shrub and aspen sucker restrictions on production of annuals	2.	1.-3.	Dimensionless	INT-1751 estimate
112		Conifer seedling restriction on production of annuals	.005	.001-.01	Dimensionless	INT-1751 estimate
113		Conifer seedling restriction on production of annuals	6.	4.-8.	Dimensionless	INT-1751 estimate
114		Unrestricted production rate of annuals	500		kg/ha/yr	Bartos and Mueggler 1981
115		Aspen restriction on perennial production	.5	.3-.7	Dimensionless	INT-1751 estimate
116		Conifer restriction on perennial production	.007	.001-.01	Dimensionless	INT-1751 estimate
117		Conifer restriction on perennial production	6.	4.-8.	Dimensionless	INT-1751 estimate
118		Annual restriction on perennial production	.7	.5-.9	Dimensionless	INT-1751 estimate
119		Shrub and aspen sucker restriction on perennial production	.5	.3-.7	Dimensionless	INT-1751 estimate

Parameter number	FORTRAN name	Definition	Value	Range	Units	Source
120		Conifer seedling restriction on perennial production	.007	.001-.01	Dimensionless	INT-1751 estimate
121		Conifer seedling restriction on perennial production	6.	4.-8.	Dimensionless	INT-1751 estimate
122		Unrestricted production rate of perennials	3,500		kg/ha/yr	Bartos and Mueggler 1981
123		Aspen restriction on shrub regeneration	4.	2.-6.	Dimensionless	INT-1751 estimate
124		Conifer restriction on shrub regeneration	6.	4.-8.	Dimensionless	INT-1751 estimate
125		Shrub restriction on shrub regeneration	.1	0-.2	Dimensionless	INT-1751 estimate
126		Shrub restriction on shrub regeneration	3.5	2.-5.	Dimensionless	INT-1751 estimate
127		Total of aspen sucker restriction on shrub regeneration	.4	.2-.6	Dimensionless	INT-1751 estimate
128		Total of conifer seedling restriction on shrub regeneration	6.	4.-8.	Dimensionless	INT-1751 estimate
129		Annual and perennial restriction on shrub regeneration	.8	.6-.9	Dimensionless	INT-1751 estimate
130		Unrestricted regeneration rate of shrub regeneration	100	75-125	kg/yr	INT-1751 estimate
131		Aspen restriction on shrub growth	.5	.4-.6	Dimensionless	INT-1751 estimate
132		Conifer restriction on shrub growth	.001	0-.01	Dimensionless	INT-1751 estimate
133		Conifer restriction on shrub growth	.5	.25-1.	Dimensionless	INT-1751 estimate
134		Shrub restriction on shrub growth and shrub mortality	.03	.02-.04	Yr^{-1}	INT-1751 estimate
135		Shrub restriction on shrub growth and unrestricted shrub growth rate	.2	.15-.25	Yr^{-1}	INT-1751 estimate
136		Total of aspen sucker restriction on shrub growth	.5	.3-.7	Dimensionless	INT-1751 estimate
137		Total of conifer seedling restriction on shrub growth	.01	0-.1	Dimensionless	INT-1751 estimate
138		Annual and perennial restriction on shrub growth	.4	.2-.6	Dimensionless	INT-1751 estimate

Bartos, Dale L.; Ward, Frederick R.; Innis, George S. Aspen succession in the Intermountain West: A deterministic model. Gen. Tech. Rep. INT-153. Ogden, UT: U.S. Department of Agriculture, Forest Service; 1982. 60 p.

A deterministic model of succession in aspen forests was developed using existing data and intuition. The degree of uncertainty, which was determined by allowing the parameter values to vary at random within limits, was larger than desired. This report presents results of an analysis of model sensitivity to changes in parameter values. These results have indicated areas of needed research. The model responds realistically to various management techniques and could be an aid to resource managers in their decisionmaking process.

KEYWORDS: simulation model, model sensitivity, FORTRAN, Forester diagrams, (fractional) factorial design, *Populus tremuloides*

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**Intermountain
Forest and Range
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Ogden, UT 84401**

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Pocket Gophers in Forest Ecosystems

**Cynthia Lea Teipner, Edward O. Garton,
and Lewis Nelson, Jr.**

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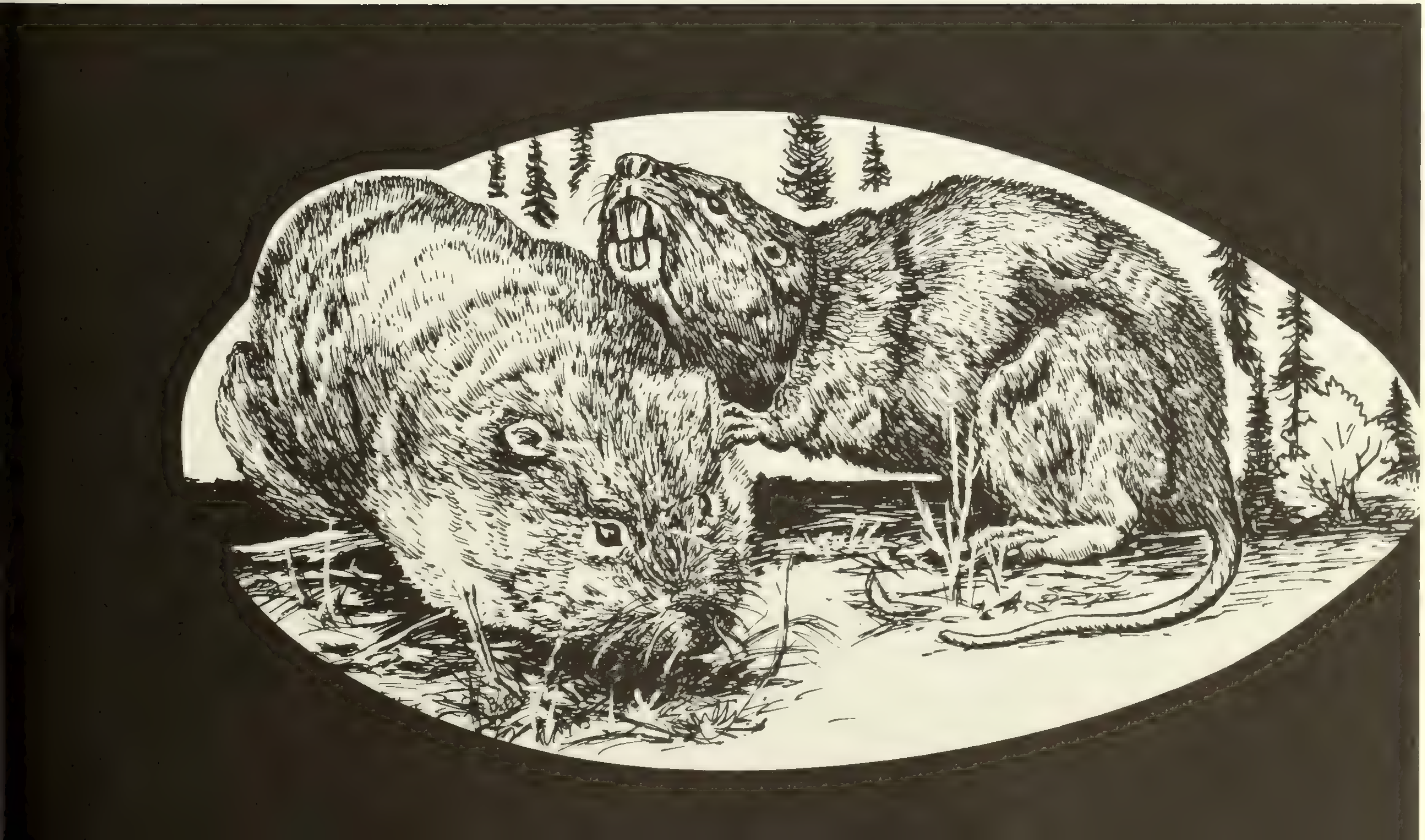

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RESEARCH SUMMARY

This publication is a state-of-the-knowledge report on available information on gopher biology, ecology, damage, and control. Habits and related problems are reviewed for gopher species throughout the United States, but attention is focused on the northwestern forest environments. A bibliography containing over 1,000 literature citations is included.

The report is not intended as a field guide for control practices, but is meant to familiarize the land manager with the nature and extent of pocket gophers, damage potential, and available control methods. It also discusses areas where research is needed.

PREFACE

The digging, burrowing, and feeding activities of pocket gophers (Geomyidae) frequently conflict with land management goals. In the Pacific Northwest, gopher depredation to conifer seedlings on forest lands is a particularly important economic concern. The following is a state-of-the-knowledge report on gopher biology, ecology, damage, and control. Gopher habits and related problems are reviewed for geomyid species ranging throughout the United States, but more attention is focused on pocket gophers found in northwestern forest environments. This report is not intended as a field guide for control practices, but is meant to familiarize the land manager with the nature and extent of pocket gopher problems, damage potential, and available control methods.

To facilitate access to existing literature, a bibliography of over 1,000 literature citations is included. This section is expanded from a bibliography compiled by Anderson and others (1976:GR). Citations are designated into categories by subject and listed alphabetically by author. Letter abbreviations are assigned to each subject category, and citations used within the text will be found by referring to the appropriate section.

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Pocket Gophers in Forest Ecosystems

Cynthia Lea Teipner, Edward O. Garton,
and Lewis Nelson, Jr.

IDENTIFYING CHARACTERISTICS

General Description

A number of distinctly subterranean attributes equip pocket gophers (Geomyidae) for their fossorial existence. These qualities developed convergently in at least five completely unrelated lineages. Characteristics other than their morphological adaptations for burrowing include reduced individual movement, distribution patterns that vary with soil conditions, parapatric distribution, and a social system in which individuals rigorously defend lone territories (Patton and Yang 1977:G).

General morphological characteristics include: compact musculature, powerful forearms, long claws on the forefeet, and sharp, curved, continuously growing incisors that aid in digging and burrowing (Tryon 1947:NH; Howard and Childs 1959:HRR; Hall and Kelson 1959:GR; Downhower and Hall 1966:DT). Gopher lips close behind the incisors preventing soil from entering their mouths when foraging and digging. Gophers have small eyes, set wide and high on their heads, and small external ears (fig. 1). Two external, fur-lined, eversible cheek pouches used in carrying food and nesting material give the word "pocket" to their name.

Among the three genera within the United States, morphological and ecological characteristics appear to be most generalized in *Thomomys* (Hill 1937:PHM). *Geomys* spp. characteristics connote a higher degree of specialization with a more massive, flattened skull, smaller eyes, inconspicuous ears, and exceedingly prominent forefeet with heavy nail and limb development (Miller 1964:DT).

Guard hairs are sparsely scattered and occur mainly in the rump region on the body and tail. They may function as sensory units to guide the gophers forward and backward through dark tunnels. The almost naked tail and feet may be thermoregulatory and the gophers respond to heat stress by increasing blood flow to these extremities (McNab 1966:GH).

The environment may play a role in fur color. Darker species occur in darker soils and lighter colored populations inhabit drier, lighter colored soils (Ingles 1950:PHM; Getz 1957:PHM; Walker 1955:DT). Gophers uncommonly display color aberrations, although several studies report various instances of pelage color mutations (Storer and Gregory 1934:PHM; McCarley 1951:PHM), including occasional sightings of albinism (LaVoie and others 1971:PHM).

Pocket gophers annually undergo variable and irregular molts. Semiannual molts result in distinctive summer and winter coats (Bailey 1915:DT; Howard and Childs 1959:HRR). Gophers may experience an early summer molt that spreads down to the tail and is evidenced by a "molt line" at various stages (Tryon 1947:NH).

The gophers occasionally produce soft squeaks, and teeth "clicking" may serve as a warning mechanism. The solitary behavior of pocket gophers may not necessitate a more complex system of vocal communication (Howard and Childs 1959:HRR).

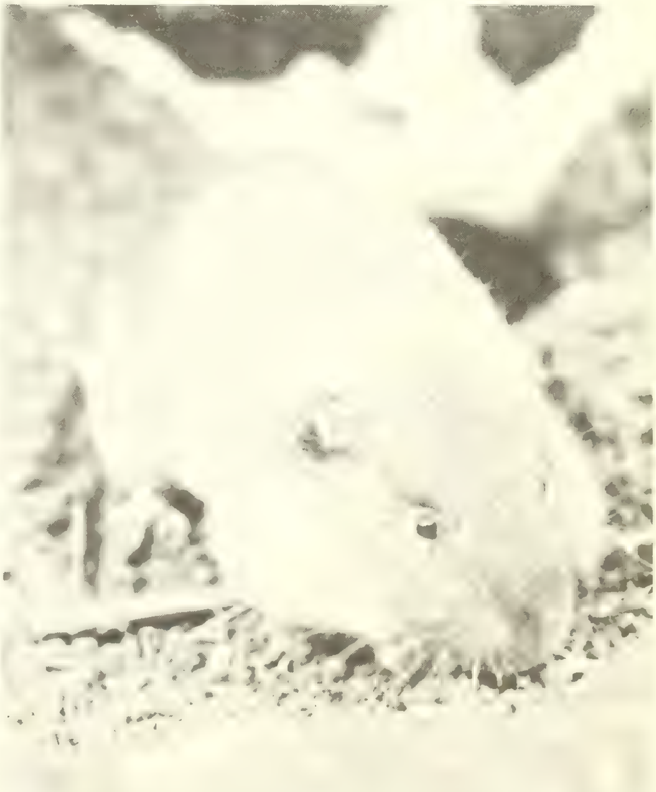

Figure 1.—The pocket gopher has small eyes, set wide and high on the head, and small external ears.

Taxonomy

Pocket gophers comprise a highly fossorial group of rodents found only in the Western Hemisphere. They occupy habitat types from sea level to above timberline. Their taxonomy is based mainly on groove patterns of the upper incisors. Classification may be complicated by groove patterns that have developed similarly in different lineages (Akersten 1973:PHM). Within this family, Hall and Kelson (1959:GR) identified eight living genera: *Thomomys, Geomys, Pappogeomys, Cratogeomys, Orthogeomys, Heterogeomys, Macrogeomys*, and *Zygogeomys*. Revised classification schemes detail only five genera, three of which occur within the United States: *Thomomys, Geomys*, and *Pappogeomys* (=*Cratogeomys*) (Russell 1968b:DT; Hall 1981:GR) (fig. 2). *Pappogeomys* and *Cratogeomys* are used interchangeably throughout this text, depending on the way individual researchers classified them.

Complex distribution patterns and extreme geographical variation of pocket gophers cause classification difficulties at the species and subspecies levels (Patton 1973:G). The three U.S. genera display varied morphological and ecological requirements. Based on these variations, Hall (1981:GR) identified five species and almost 300 subspecies of *Thomomys* within North America. In addition, he lists seven species and 38 subspecies of *Geomys* and nine species and 54 subspecies of *Pappogeomys*. Only one species of *Pappogeomys* occurs in the United States.

Characteristics of Age, Sex, and Development

Proper sexing and aging is important in the assessment of gopher population dynamics. Investigators generally use characteristics denoting reproductive activity as an indicator of age. Gophers are normally separated into two age classes: young and adults. Researchers have not developed reliable techniques for aging animals beyond 1 year of age (adulthood) (Hansen and Reid 1973:DT).

The presence of a pubic gap in a female generally indicates participation in at least one breeding cycle. The pubic gap forms with the resorption of the pubic symphysis just prior to the first breeding season. At this point the female is termed adult. Investigators term animals lacking such a gap as young (Hisaw 1924:PHM; Miller 1946:RGA; Hansen 1960:RGA). Hansen (1960:RGA) also found the size of the uterine horns to be of limited value in distinguishing young from adults or determining reproductive activity. The horns remain small in young until approximately 6 to 7 months. The presence of placental scars, lactation or enlarged mammary tissue, and size of uterus in nonpregnant females

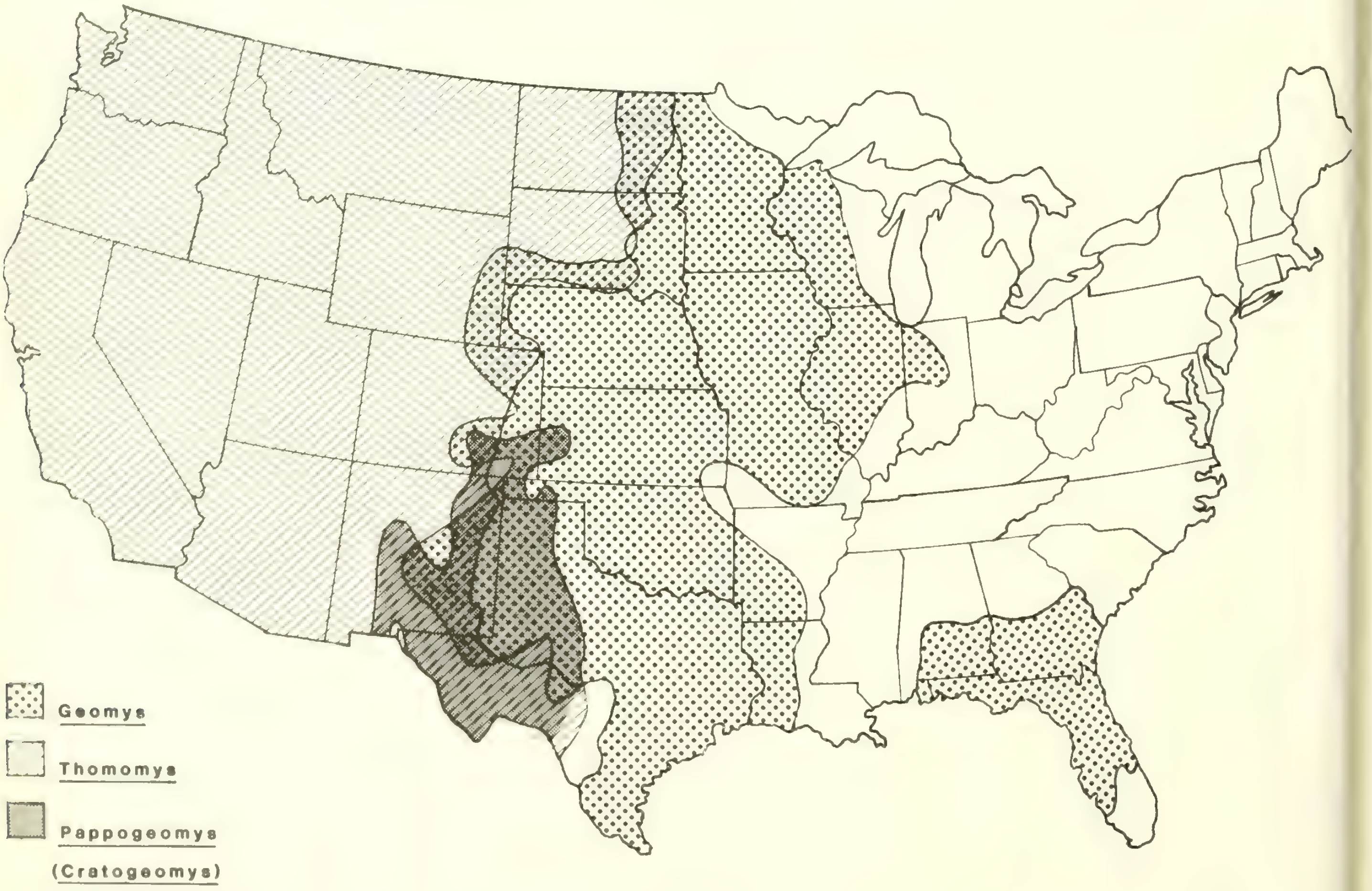

Figure 2.—General distribution of the three genera of pocket gophers within the United States. Prepared from distribution information in Hall (1981:GR).

give further evidence of past and present reproductive activity (Lay 1978:RGA).

Male aging criteria are more ambiguous. Investigators consider males producing sperm or living through at least one breeding season as adults, and class nonsperm producers as young (Vaughan 1967:DT). The position, size, and condition of the testes often serve to indicate male status (Hansen 1960:RGA; Vaughan 1967:DT; Brown 1971:RGA; Lay 1978:RGA). The length of the baculum also serves as a distinguishing characteristic up to age 7 months (Vaughan 1967:DT). Overall baculum length varies considerable among species (Ingles 1965:DT; Vaughan 1967:DT). Hansen (1960:RGA) provides data on age-length relationships for *T. talpoides* in Colorado.

In Florida, Brown (1971:RGA) distinguished three age groups (juveniles, subadults, and adults) of *G. pinetis* based on body size and condition of molt. Howard and Childs (1959:HRR) also used characteristics of pelage but found it relevant only for the very young. They used body length and weight to age *T. bottae mewa* in California up to age 3 or 4 months. Weights fluctuated widely after that. They distinguished 8- to 10-month-old males from 20- to 22-month-old males using body weights. Body length was more diagnostic for females. Adult males usually weigh more than adult females (Howard and Childs 1959:HRR; Wilks 1963:HRR; Hegdal and others 1965:NH; Best 1973:DT; Reid 1981:RGA).

Difficulty is encountered in the field when trying to distinguish young from adults. Researchers can distinguish between young and adult males by palpation of the os penis (baculum). Aging of females is considerably easier through external examination of the pubic gap. Distinction becomes increasingly difficult as physical development progresses (Hansen 1960:RGA).

Table 1.—*Age indicators for captive northern pocket gophers* (T. talpoides) *in Utah*[1]

Age	Description
Days	
1	Hairless; eyes visible as dark spots under skin; pinnae pinhead-sized buds on side of head.
9	Dorsal pelage grey-black; sparse white ventral hair; both upper and lower incisors gapped; young move about cage predominatly using a backward crawl.
16	Incisors gap closed; foreclaws pronounced; pinnae protrude from head; young move about actively.
17	Solid food eaten.
20	Pockets visible but appear closed at exterior; auditory canal closed.
23	Foreclaws 0.16 inches (4 mm) long.
24	Eyes closed; ears probably closed; pockets appear open at exterior; postjuvenile molt in progress-brown replacing grey-black in dorsal pelage.
26	Eyes, ears open.
39	Pouches used to carry food.
60	Fighting among siblings; separation required.
100	Immature molt into adult pelage up to half completed.

[1] Reproduced from Anderson (1978:RGA).

Newborn pocket gophers are blind and naked (Hill 1937:PHM). Andersen (1978:RGA) details developmental characteristics and rate of growth for *T. talpoides* based on laboratory observations (table 1). The average weight at birth of individuals in litters of five was 0.126 oz (3.58 g), while in litters of six, young averaged 0.098 oz (2.77 g) each. Animals apparently reached adult size in 100 days. Reid (1981:RGA) observed that *T. talpoides* in Colorado averaged four young per litter with individuals weighing approximately 0.1 oz (4 g) each at birth. Individuals did not attain a "near-adult" weight of 2.6 oz (75 g) until approximately 180 days. Reid claimed young became vulnerable to trapping at 1.4 oz (40 g) or about 50 days. He suggested the delaying of annual recruitment measurements until fall when all current young attained a trappable size. Barnes (personal communication, 1982), however, believes gophers weighing less than 1.4 oz (40 g) could be captured.

REPRODUCTION

The breeding season for pocket gophers varies throughout their range and depends on physical characteristics of the environment (table 2). Gophers take advantage of abundant food periods to fulfill energy requirements. Both mother and young adapt cycles to maximize survivability. *T. bottae novis* may breed year-round in California. The major reproductive effort, however, takes place in spring, coinciding with a period of abundant green growth and optimum soils for burrowing (Miller 1946:RGA). Andersen and MacMahon (1981:RGA) studied the energy demands of pocket gophers in Utah and energy supplied by various habitat types, and concluded that *T. talpoides* females advantageously delay breeding until a relatively snow-free period when aboveground plants again become available. Reproduction, however, can occur before snowmelt. In a Colorado study, Hansen (1960:RGA) found dead young in snow nests above the ground. Age, microclimate, population characteristics (that is, availability of males), and recent reproductive history can influence the actual time of conception (Desy and Druecker 1979:RGA). An extensive population dynamics study on Colorado rangelands showed that most pocket gophers breed during 4 to 5 months from the beginning of March to the end of June or July (Reid 1973:RGA, 1981:RGA). The majority of births take place between the beginning of May and the end of June. This extended period results from the presence of two classes of reproducing gophers: adults older than a year that bear young first in the spring; and young of the previous year that bear during late spring and summer.

Some studies indicate that breeding or sexual maturity occurs earlier in females than in males (Wilks 1963:HRR; Lay 1978:RGA). However, Tryon (1947:NH) reported that males came into the breeding condition first. The age at which females become a reproductive

Table 2.—*Fecundity rates among pocket gophers by area and habitat type*

Species	Habitat	Location	Breeding season	Litter size	Number litters/ year	Source
Thomomys talpoides	Mountain meadow	Colorado	Mid-March—Mid-May	4-5	1	Hansen 1960:RGA
		Bridger mts., Montana	Mid-April—Mid-May	4.4 ±.13	1	Tryon 1947:NH
		Utah	Early summer	5-6	1	Andersen and MacMahon 1981:RGA
		Utah	Early summer	3.23	1	Ellison and Aldous 1952:HRR
Thomomys talpoides quadratus	Mountain meadow	Oregon	Spring and early summer	5-10 (6.6)	—	Moore and Reid 1951:HRR
	Fruit orchards surrounded by uncultivated pasture	Oregon	Peak: Mid-March	5-9	2	Wight 1930:RGA
Thomomys bottae	Annual grassland	California	Late Jan.—April	4.6	1-2	Howard and Childs 1959:HRR
	Mountainous area	South central Colorado	March—August	3.5 ±1.2	1	Vaughan 1967:DT
Geomys bursarius	Shortgrass prairie	Colorado	April—May	3.5	1	Vaughan 1962:RGA
	Sandhill	Texas	Oct.—June	—	2-3	Wilks 1963:F
	Rangeland	Texas	Feb.—Aug.	2.7	1-2	Wood 1949:RGA
Geomys pinetis	Tampa Bay area	Southern Florida	Year-round Peaks: June—July Feb.—March	1-3 (1.74)	2-3	Brown 1971:RGA

part of the population varies among species and locale. Females reach puberty as early as 3 months (Miller 1946:RGA; Wood 1949:RGA; Wilks 1963:HRR). Brown (1971:RGA) reported *G. pinetis* became sexually mature at 4 to 6 months. Vaughan (1962:RGA) reported an 8-month span prior to puberty for *G. bursarius*.

Limited information exists on gestation. Estimates vary from 18 to 30 days for *Thomomys* (Scheffer 1938:RGA; Howard and Childs 1959:HRR; Reid 1973:RGA). Schramm (1961:RGA) observed gestation to last 19 days for *T. bottae* in the laboratory. Andersen (1978:RGA) determined an 18-day gestation for captive *T. talpoides*.

Adult animals (*Thomomys* spp.) produce only one litter per year on most western range and forest lands. Animals from these litters will not mature sexually until the following year. Reasonably stable reproductive patterns are genetically determined, but age and seasonal environmental conditions can influence fertility (Miller 1946:RGA) (table 2). Litter size varies with locality and habitat type Wight 1930:RGA; Tryon 1947:NH; Aldous 1957:F; Reid 1973:RGA, 1981:RGA). Females bear from three to more than six young at a time. Numerous authors have reported average litter size (particularly for *Thomomys* spp.) for a variety of habitats (Tryon 1947:NH; Wirtz 1954:RGA; Hansen 1960:RGA; Hansen and Ward 1966:HRR; Youmans 1979:HRF; Andersen and MacMahon 1981:RGA).

Extended breeding seasons may occur in areas with stable climates. *T. bottae novis*, living in the irrigated fields of the Sacramento Valley, bred year-round and produced up to three litters annually with four to six individuals in each (Miller 1946:RGA). In contrast, Miller found that in northern California at higher elevations gophers generally restricted their breeding to spring. *Geomys bursarius* breeds over a longer time in the southern part of its range (Hisaw 1925:PHM). Farther north, females do not usually mature sexually until the year after birth.

Brown (1971:RGA) reported the lowest litter sizes for any species of pocket gopher. *G. pinetis* produced from two to three litters annually with one to three young born in each. This species displayed an unusually low turnover rate. A high rate of survival apparently compensated for low reproduction.

Sexual development, fertility, and nutritional factors often correlate positively. Hansen (1960:RGA) noted an increase in sexual organ development and breeding activity when *Thomomys* diet consisted primarily of alfafa roots. Miller (1946:RGA) reported significantly more breeding taking place in summer on irrigated land than on nonirrigated. Reproduction depended greatly on soil moisture and green vegetation. On a chemically treated Colorado range, Hansen and Ward (1966:HRR) reported that female pocket gophers produced slightly smaller mean litter sizes than females on untreated range. Herbicide use reduced broadleaf forb production on the treated range.

DISPERSAL

Weaned pocket gophers may disperse from the nest at about 5 to 6 weeks of age (Miller 1946:RGA; Brown 1971:RGA). Howard and Childs (1959:HRR) reported dispersal of *T. talpoides* at about 8 weeks. Other species (*G. bursarius*) mature sexually as early as 3 months and disperse (Wood 1949:RGA). Young and mother coexist peaceably until increasing agonistic behavior forces dispersal (Wight 1930:RGA). Distances recorded for gophers when dispersing or traveling vary (table 3). Howard and Childs (1959:HRR) noted that some dispersal occurred over the surface. Marked animals traveled at least 400 ft (122 m) before recapture with funnel nets.

Hickman and Brown (1973:B) recorded a maximum dispersing distance of 260 ft (79 m) for *G. pinetis*. The gopher spent at least 20 minutes above ground. Vaughan (1963:M) noted that *T. talpoides* moved up to 1,000 ft (305 m) at a time with an average of 545 ft (166 m). In 1967, Vaughan (1967:DT) compared the distance traveled by released individuals of *T. talpoides* and *T. bottae*. *T. talpoides* moved a mean distance of 785 ft (239 m) although one individual went 2,590 ft (789 m). *T. bottae* dispersed a mean distance of 197 ft (60 m). One individual traveled a maximum of 900 ft (274 m).

Burrowing through snow facilitates pocket gopher dispersal. Animals gain access over obstacles normally blocking movement during snow-free periods (Hansen and Reid 1973:DT). Extensive movement may take place in the snowpack (Hansen 1962:M; Ingles 1949:M).

Gophers may rapidly repopulate control areas, especially when improperly treated (Keith 1961:CHH; Buchner and Rorabaugh 1979:DTF). On the Ashton District in Idaho, overwinter reinvasion occurred on 30-acre (12-ha) clearcuts when surrounding timber was not treated at least 60 ft (18 m) past the clearcut boundary (Birch 1982, personal communication). Uncut buffer strips may slow reinvasion. In Colorado, gophers repopulated fall-trapped 1-acre (0.4-ha) plots by the following summer. Hansen and Reid (1973:HRR) suggested a 200-ft (61-m) buffer zone to prevent reinvasion by gophers burrowing in snow. Gophers also exhibit homing tendencies after displacement (Howard and Childs 1959:HRR).

ECOLOGICAL DISTRIBUTION

In general, unsuitable soil and/or flora types limit pocket gopher distribution. Soil type tolerance, climatic conditions, or intraspecific competition may limit the range of individual species (Miller 1964:DT). McNab (1966:GH) suggested that minor physiological differencess between species could influence distribution.

The gophers display physical and behavioral adaptations best suited to their respective habitats (Buchner and Rorabaugh 1979:DTF). Species consequently maintain almost total allopatric or parapatric distributions (Bailey 1927, 1931:GR; Kennerly 1959:DT; Vaughan 1967:DT; Best 1973:DT; Dalquest and Kilpatrick 1973:DT; Bradley and others 1974:PHM). Allopatry generally prevails where ranges meet, although a local population may include different species. Vaughan (1967:DT) described range overlap between *T. talpoides* and *T. bottae* in Colorado. Populations of one species coexisted with individuals or colonies of the other; however, both populations maintained reproductive isolation. Vaughan believed species achieved separation through differences in dispersal abilities and reproductive cycles.

Patton (1973:G) described hybridization occurring among *T. bottae* and *T. umbrinus* in southern Arizona but found no evidence of genic introgression. Sterility in male hybrids coupled with reduced reproductive potential in female hybrids established a "postmating barrier." Patton and Yang (1977:G) hypothesized that chromosomal organization in *T. bottae* was more important than genic variation in events leading to speciation and reproductive incompatibility.

Contiguous allopatry may occur in some areas with the competitive exclusion of one species by another. Miller (1964:DT) found a pattern of hierarchy established among four species of gophers in Colorado. Populations with the largest individuals outcompeted other populations for superior habitat. Tolerance to the soil type dictated a species' ability to compete. Superior species with the most restrictive niche requirements displaced other species to less favorable habitats. Patton (1973:G) observed that *T. umbrinus* appeared limited in distribution as a result of direct competition from larger, more aggressive members of *T. bottae*. However, he suggested that limited soil tolerance and poor physiological adaptability of *T. bottae* prevented them from displacing *T. umbrinus* even further.

In general, larger species are more restricted by soil type and occur at lower elevations in deeper, more tractable soils. Smaller species inhabit higher elevation, and shallower, rocky soils (Davis 1938:PHM; Dalquest and Scheffer 1944:DT). But Tryon and Cunningham (1968:NH) found smaller individuals in deeper, low elevation soils while larger bodied animals inhabited high elevation habitat. In this case, animal size seemed related to population density and the quality of forage in animal diets. Larger species may displace smaller ones where ranges meet (Miller 1964:DT; McNab 1966:GH). In a conflict situation, larger individuals may dominate, but smaller species forced to occupy less favorable habitats may more readily adapt (Howard and Childs 1959:HRR). However, Miller (1964:DT) did not find that larger individuals dominated. *Pappogeomys castanops* was competitively inferior to the smaller members of *G. bursarius*.

Extreme temperatures may limit fossorial rodents in shallow soils (Howard and Childs 1959:HRR; Kennerly 1964:BE). Gophers excavate deeper during hot and dry periods (Crouch 1933:DC; Wilks 1963:HRR). In this way, they may avoid heat stress. Larger animals may burrow proportionately deeper because of their size (Kennerly 1954, 1959:DT; McNab 1966:GH). Howard and Childs (1959:HRR) reported that burrows tended to collapse when constructed in soils averaging 4 inches (10 cm) or less in depth.

Table 3.—*Movements and home range sizes among pocket gopher populations*

Species	Location	Method	Scope of study	Distance traveled ♂	Distance traveled ♀	Distance traveled Juvenile	Distance traveled Average	Distance traveled Maximum	Home range ♂	Home range ♀	Home range Juvenile	Home range Average	Source
				Meters					Square meters				
Thomomys Talpoides	Utah experimental forest	Extensive trapping on arranged plots	Annual shifts				10	>40					Andersen and MacMahon 1981:RGA
			Over winter			99	15						
	Colorado: a) Mima mound habitat	Mark recapture with maximum distances between captures		100	81								Hansen 1962:M
	b) Thurber-fescue-forb rangeland		Successive captures - snow-free periods	43	83				36				Hansen and Reid 1973:DT
	Northern Idaho Forb-shrub complex	Radio-isotope tracking	Daily	3	4	4	3–13		356	281	261	606	Kuck 1969:DTF
	Colorado range	Mark recapture					238	785					Vaughan 1967:DT
T. talpoides and T. mazama	Central Oregon Logged– slash burned	Winter cast survey	April					121					Barnes 1974:HRF
Thomomys bottae	Colorado range	Mark recapture					60	273					Vaughan 1967:DT
	California range	Mark recapture	Winter & Spring						818	394			Howard and Childs 1959:HRR
Thomomys monticola	Sierra Nevada mountain meadow			36		121			24-451	27-572	28-572		Ingles 1952:HRR
Geomys pinetis		Captured and release					78						Hickman and Brown 1973:B

Pocket gophers prefer light, friable, well-drained soils. They select porus, sandy soils. Clay types may be too compact for burrowing. (Davis and others 1938:S; Davis 1940:DT; Kennerly 1954:DT, 1958:NH, 1964:BE; Howard and Childs 1959:HRR; Wilks 1963:HRR; Miller 1964:DT; Andersen and MacMahon 1981:RGA). Andersen and MacMahon (1981:RGA) proposed differences in "burrowing efficiency" as opposed to agonistic displays of behavioral dominance as the best explanation for parapatry among pocket gophers.

Gophers may live in soils where mean moisture content ranges from less than 10 to more than 50 percent (Hansen and Beck 1968:HRR). Andersen and MacMahon (1981:RGA) noted that *T. talpoides* apparently could not dig in dry, compact soils and showed aversion to burrowing in wet soils. Burrowing became impossible when moist soils froze. Youmans (1979:HRF) noted that swales in Montana contained too much moisture for gopher inhabitance until late summer. Dispersing juveniles would then establish territories in those areas. Ingles (1949:M) noted that pocket gophers abandoned burrows during active snowmelt and/or runoff. Narrow strips of wet, soggy soil often acted as barriers to dispersal.

Pocket gophers require high rates of gas exchange in their burrows (Kennerly 1964:BE; McNab 1966:GH). Clay soils with high water-holding capacity may not permit an adequate exchange of oxygen and carbon dioxide (McNab 1966:GH).

Chemical properties of the soil may not directly affect pocket gopher distribution except through modification of existing soil structure and plant composition or production. Soil fertility may become increasingly important as it affects the presence or absence of preferred vegetation (Hansen and Reid 1973:DT). Davis (1938:PHM) placed little importance on soil pH.

Patterns of distribution reflect other physiological and morphological adaptation by gophers to their environments. Bradley and others (1974:PHM) compared metabolic rates and thermal conductance between mountain meadow dwelling species (*T. talpoides*) and gophers (*T. umbrinus*) living in the deserts of Nevada. The smaller size, longer tails, and reduced insulation of *T. umbrinus* contributed to lower metabolic rates and higher thermal conductance. The investigators felt these adaptations to different environmental conditions explained their ecological distributions.

BEHAVIOR

Food Habits

Pocket gopher food preferences show marked geographic variation. Strictly herbivorous gophers use all the plant parts during the course of active year-round feeding (Ward 1973:FF). Aldous (1951:FF) reported pocket gophers feeding in the immediate vicinity of their mounds but could not determine how far gophers ranged to forage aboveground. Ward (1960:FF) noted that pocket gophers gathered aluminum-coated grain on the surface, indicating that aboveground foraging may be more extensive than previously thought. The Colorado Cooperative Pocket Gopher Project (1960:DT) also documented aboveground feeding in summer.

Tryon and Cunningham (1968:NH) believed gophers could "select" foods based on proportionately higher quantities of proteins and fats found in their stomachs than in habitat vegetation. Some species select and rely on forbs, as indicated by studies in Colorado (Keith and others 1959:DC; Ward 1960:FF; Ward and Keith 1962:FF; Vaughan 1967:FF; Turner 1973:HRR), Montana (Tryon 1947:NH), Oregon (Moore and Reid 1951:HRR), and Utah (Aldous 1951:FF). Grasses, even if abundant, often comprise only a minor proportion of *Thomomys* diet (Ward 1973:FF). In feeding trials of *T. talpoides*, Teitjen and others (1967:HRR) reported that only those grasses high in moisture content or with food storage structures could provide diets capable of sustaining gophers. Vaughan (1967:FF) said grasses comprise 72 percent of the vegetation in his Colorado study area, but composed only 30 percent of the annual diet for *T. talpoides*.

In south-central Oregon, *T. mazama* preferred the annual forbs that comprised 57 percent of the vegetative cover, but they subsisted on perennial grasses when forbs were not available (Burton and Black 1978:FF). Preferred forbs include common dandelion (*Taraxacum officinale*), lupine (*Lupinus* spp.), penstemon (*Penstemon rydbergii*), western yarrow (*Achillea millefolium lanulosa*), agoseris (*Agoseris* spp.), hairy goldaster (*Chrysopsis villosa*), slenderleaf gilia (*Gilia linearis*), aspen peavine (*Lathyrus leuconthus*), fremont geranium (*Geranium fremontii*), and beauty cinquefoil (*Potentilla pulcherrima*) (Ward 1960:FF, 1973:FF; Hansen and Ward 1966:HRR).

Forbs and shrubs constituted 67 percent of the annual diet on shortgrass prairie in Colorado. Pocket gophers relied most heavily on pricklypear (*Opuntia polyacantha*), which serves as a primary source of nutrition and water. A combination of weather and intensive gopher consumption of pricklypear probably influences local abundance of this plant (Vaughan 1967:FF). On forest lands in California, *T. monticola* preferred lupine but consumed proportionally high quantities of whitethorn ceanothus (*Ceanothus cordulatus*), gooseberry (*Ribes roezoli*), and some red fir (*Abies magnifica*) (Buchner and Rorabaugh 1979:DTF).

Pocket gophers are adaptable in their feeding habits, and food preferences are responsive to changes in the availability of forage species (Ward 1973:FF; Burton and Black 1978:FF). They primarily select green, succulent, aboveground leaves and stems during the growing season. Depending on the habitat, underground plant parts, roots, or grasses become most important during the dormant season (Ward 1960:FF; Myers and Vaughan 1964:FF; Burton and Black 1978:FF).

The variable feeding preferences of pocket gophers do not preclude any plant species from attack in certain situations (Canutt 1970:DTF; Working Group of the Northwest Forest Pocket Gopher Committee 1976:DTF; Crouch 1979:DC). Studies of gopher preferences for specific conifer species showed weak correlations or none at all. Crouch (1971:DTF) found no significant difference in gopher preference among ponderosa pine (*Pinus* *ponderosa*), jeffrey pine (*P. jeffreyi*), and lodgepole pine (*P. contorta*).

Andersen and MacMahon (1981:RGA) studied energy requirements of *T. talpoides* and relationships between forage availability in different environments along a successional gradient. The species displayed catholic food habits and ate anything nonnoxious. High energy costs of securing foods made these actions seem reasonable.

Pocket gophers store food in lateral tunnels that branch from the main runway. These food caches may exceed their needs (Ward 1973:FF). Ward located the caches of *T. talpoides* in Colorado 3 to 4 inches (8 to 10 cm) below surface. Idaho studies on *T. talpoides* showed caches to be deeper, usually from 7 to 12 inches (17 to 30 cm).

Activity Periods

Gophers remain active year-round (Scheffer 1931:B; Hansen and Reid 1973:HRR; Andersen and MacMahon 1981:RGA). In temperate regions, gophers appear to be most active during spring and fall (Scheffer 1931:B; Criddle 1930:NH). In drier areas, activity peaks during the rainy season (Miller and Bond 1960:B). Miller (1948:B, 1957:BE) found digging activity related to soil moisture in the Sacramento Valley and other climatically similar regions. Activity remains lowest in summer and early fall, then rises abruptly after the first heavy autumn rains. Kuck (1969:DTF) used radioisotope labeling on gophers to follow their activities throughout the summer. He noted that activity occurred 24 hours a day but intensified during daytime. He also related intensified seasonal activity with increased soil moisture. More active females and juveniles moved farther than adult males.

Miller and Bond (1960:B) discovered that mountain populations of *T. talpoides* remained inactive in late spring and summer during presumably ideal soil moisture and burrowing conditions. Seasonal activities appeared to be the result of changes in breeding behavior and feeding habits.

Howard and Childs (1959:HRR) found that pocket gophers maintained deeper burrows during hot, dry summer conditions. They observed some gophers in a "profound sleep" under laboratory conditions. They speculated that *Thomomys* might undergo a period of torpidity when conditions become exceedingly warm or dry. Kuck (1969:DTF) found that radiotracked gophers often became inactive for long periods during late summer. Some underwent a period of estivation. One adult male remained inactive for 13 days in mid-August.

The literature contains limited knowledge of daily activity patterns of pocket gophers. Andersen and MacMahon (1981:RGA), employing radiotelemetry, found *T. talpoides* remaining active during all hours of the day. They could not define the type of activity being performed but assumed gophers spent 50 percent of each day in nonresting. Two weeks of continual monitoring revealed that individuals spent approximately 34 percent of their time in activity (Vaughan and Hansen 1961:PHM). Tryon (1947:NH), finding that *T. talpoides* in Montana excavated about 60 percent more soil at night, deduced that most activity probably occurred at dawn and at dusk. Hungerford (1976:FF), however, disclaimed reliance on surface sign as an indicator of total daily activity patterns based on laboratory findings. Mound building occurred most frequently in the morning and at night. Other activities took place around the clock with intermittent rest. Gophers, when secure in their burrows, may not leave any aboveground sign for months. Kuck (1969:DTF) found activity varied throughout the summer, although the actual distances traveled by gophers did not change. Evidence indicated that activity did not correlate with seasonal movement. Environmental conditions influenced daily activity but not total distance traveled to defend territory. In addition to defense, movement in search of food may continue regardless of environmental conditions.

Territoriality

Pocket gophers actively defend individual territories most of the year. Their home ranges usually correspond with the burrow system. Kuck (1969:DTF) and others noted that home ranges tend to be linear in shape, with activity usually concentrated in certain portions of the territory. Hansen and Remmenga (1961:F) found that relationships existed between pocket gopher densities and the size and distribution of territories. At low populations, territories remained clustered with a good deal of vacant land between colonies. At intermediate densities individual territory size approaches a normal distribution. A regular distribution pattern with territories similar in size existed at high densities.

Males generally maintain larger territories than females (Kuck 1969:DTF). In California, Howard and Childs (1959:HRR) estimated that burrow systems covered 8,860 ft^2 (823 m^2) for males and 4,260 ft^2 (396 m^2) for females. Larger territories existed when population densities were lower. On Black Mesa, open tunnel length for *T. talpoides* ranged from 80 to 105 ft (24 to 32 m). Individual burrow systems could cover some 6,530 ft^2 (600 m^2) (Hansen and Reid 1973:HRR).

Dispersing subadults quickly take over vacated burrow systems. Young animals looking for a home site may occupy marginal habitats until better areas become available when older animals die or move. Howard and Childs (1959:HRR) believed that *T. talpoides* established territories for a lifetime in the California foothills where snow is uncommon. Hansen and Reid (1973:DT) noted that gophers abandoned belowground territories during Colorado winters and burrowed solely in the snowpack. When forced back to their subterranean habitats, gophers did not necessarily return to previously occupied burrows. Similarly, gophers displaced by snowmelt and rising groundwater tables did not always return to their original systems.

Gophers become tolerant enough of one another to intermix in individual burrow systems only during the breeding season. Investigators most often recorded plural occupancy of burrow systems by the same species during this time (Miller 1946:RGA; Hansen and Miller 1959:B; Howard and Childs 1959:HRR; Vaughan 1962:RGA). Plural occupancy involving two adult individuals of different species happens less often. Vaughan (1967:DT) reported three separate cases of multispecies occupancy in Colorado. He concluded that inter- and intraspecific tolerance did not differ during periods of breeding.

BURROW SYSTEMS

Numerous authors describe the burrow systems of various species (Scheffer 1931:B, 1940:BE; Tryon 1947:NH; Smith 1948:BE; Downhower and Hall 1966:DT; Hansen and Reid 1973:HRR; Hickman 1977:BE). Best (1973:DT) compared and contrasted characteristics of tunnel systems and mounds of *T. bottae, P. castanops*, and *G. bursarius*. He felt confident in identifying species' presence by observing mounds and other ground surface features.

Generally, main tunnels run parallel to the ground. Downhower and Hall (1966:DT) classified them as either "deep" or "subsurface." Main tunnels contain numerous lateral branches that often terminate at the surface in characteristic fan-shaped mounds.

Tunnel diameters vary between 2 and 4 inches (5 and 10 cm) depending on species and animal size (Scheffer 1940:BE; Smith 1948:BE; Moore and Reid 1951:HRR; Best 1973:DT; Hansen and Reid 1973:DT). Best (1973:DT) used tunnel diameter coupled with depth and shape characteristics to distinguish burrow systems of different species.

"Plugs," although difficult to see, also indicate gopher presence. Plugs remain after gophers seal feeding tunnels or repair open breaks in their burrows at ground level (Hansen and Reid 1973:DT; Buchner and Rorabaugh 1979:DTF).

Pocket gophers use subsurface tunnels for feeding. Such tunnels usually occur in the top 4 to 12 inches (10 to 30 cm) of soil. Soil and vegetation structure may control tunnel depth (Davis and others 1938:S; Moore and Reid 1951:HRR; Downhower and Hall 1966:DT; Hansen and Reid 1973:DT). Tryon (1947:NH) reported *T. talpoides* constructed feeding burrows 12 to 16 inches (30 to 40 cm) below patchy areas of sagebrush. Tunnel length varies and can run several hundred feet in all (Moore and Reid 1951:HRR; Downhower and Hall 1966:DT). Richens (1966:B), following and recording the activities of one *T. talpoides* released in Utah, noted that this gopher constructed 480 ft (146 m) of feeding tunnels over 5 months. Tryon (1947:NH) believed pocket gophers could maintain a maximum of 150 to 200 ft (45 to 60 m) of feeding tunnels. Food availability in an area may partially determine the degree of burrowing activity (Scheffer 1931:B; Moore and Reid 1951:HRR).

Deep tunnels often lead to nests and may attain depths of 5 ft (1.5 m) or more (Moore and Reid 1951:HRR). Nests are usually chambers lined with dry leaves and grasses (fig. 3). In Kansas, Downhower and Hall (1966:DT) noted that gophers did not construct nests at the deepest point of the burrow system. A run usually extended deeper from a chamber, suggesting that it may serve to drain other portions of the burrow system.

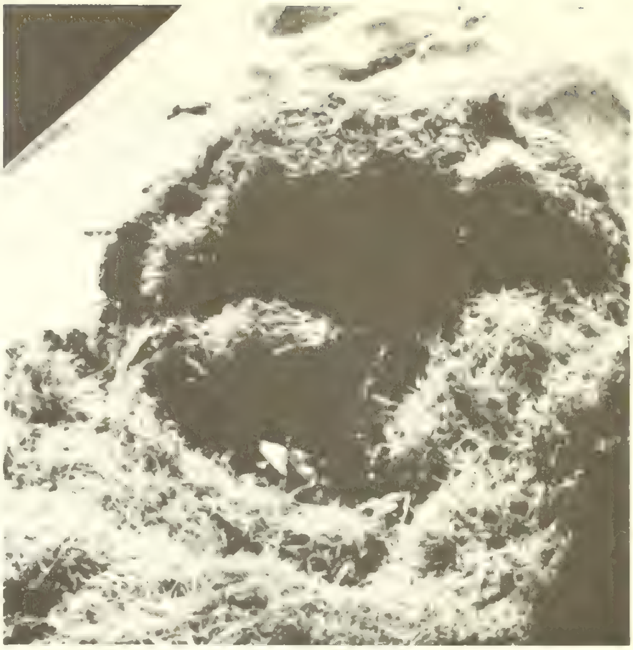

Figure 3.—A winter nest made by the gopher under the snow.

Gophers burrow through the snowpack in winter (Scheffer 1931:B; Ellison 1946:S; Tryon 1947:NH; Miller 1948:B; Ingles 1949:M, 1952:HRR; Hansen and Reid 1973:DT). Snow tunnels may reach a length of more than 100 ft (30 m) (Ingles 1949:M; Hansen and Reid 1973:DT). Gophers form soil casts by pushing soil up from their burrow system into tunnels dug in the snow. These cylindrical casts settle to the ground during spring snowmelt, leaving evidence of winter activity (Hansen and Reid 1973:DT) (fig. 4).

Several reports discuss the microenvironment of the burrow system including characteristics of temperature, light, and humidity. Past research includes: the effects of microclimate on thermoregulatory capacities of pocket gophers (Kennerly 1964:BE; McNab 1966:GH; Gettinger 1975:PHM); comparison of metabolic and thermoregulatory patterns between desert and mountain species of *Thomomys* (Bradley and others 1974:PHM); and examination of the physiological and morphological differences and adaptation of one species in two distinct environments. Andersen and MacMahon (1981:RGA) related features of microclimate and metabolic rates to the energy requirements of *T. talpoides* and subsequent survival limitations.

Other animals will use the gopher burrow systems, but the extent of interaction between gophers and other species remains unclear. Hickman (1977:BE) lists the parasitic and nonparasitic invertebrates, amphibians, reptiles, and small mammals found in these systems and discusses some interactions observed in the laboratory.

Vaughan (1961:BE) recorded 22 species of vertebrates using geomyid burrows for shelter, protection, or as access routes for feeding. He noted that geomyid rodents and tiger salamanders (*Ambystoma tigrinum*) appear to be tolerant of each other. In fact, the existence of the

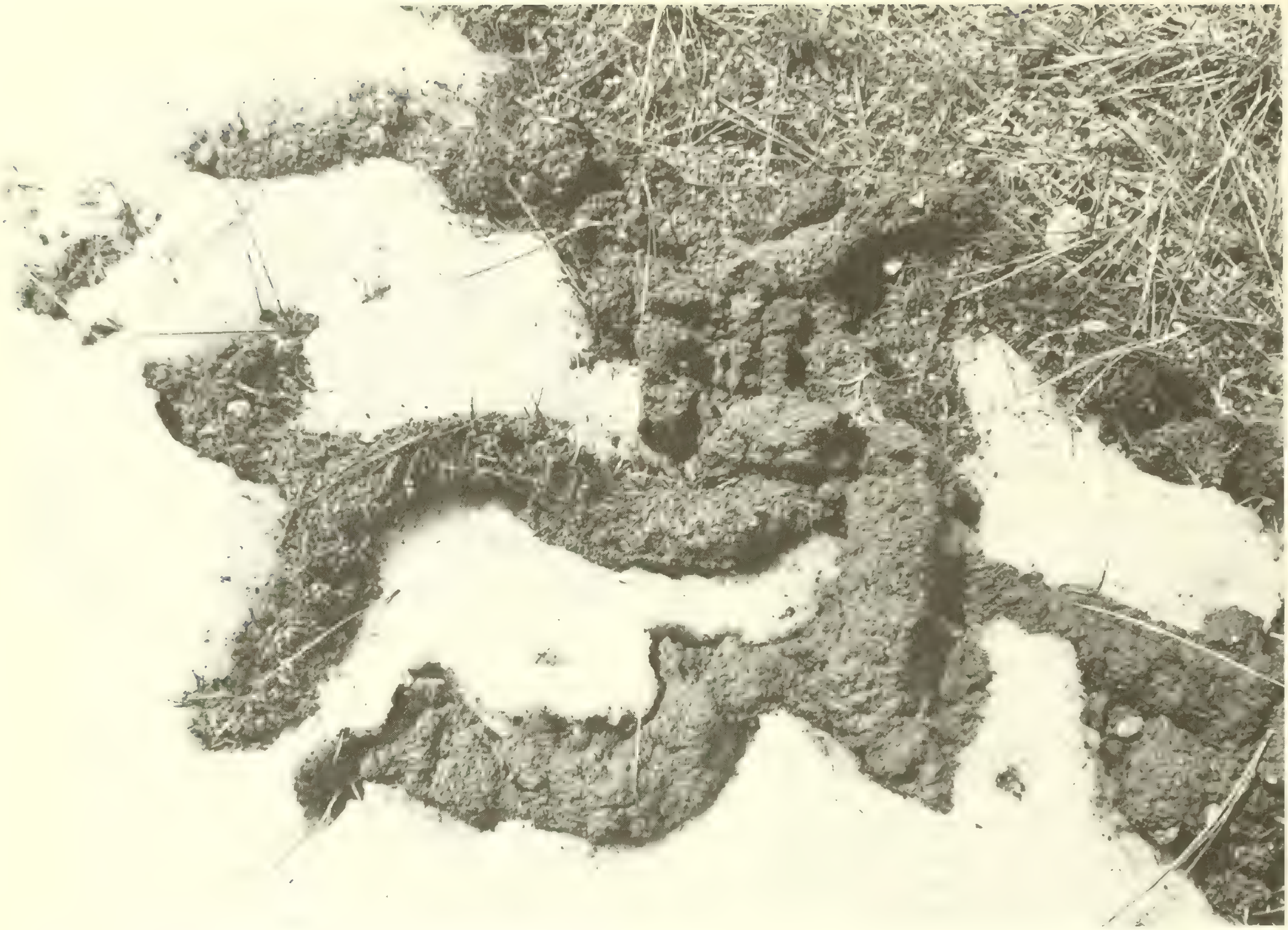

Figure 4.—Winter casts are left intact as the snow melts.

salamander in certain semiarid habitats may be dependent on the presence of burrows. In other instances, gophers and other animals may compete directly for food and space (Turner 1973:HRR).

ABUNDANCE AND POPULATION FLUCTUATION

Pocket gopher populations may change due to the effects of weather, soil, flora, recruitment, competition, diseases, natural enemies, and land use practices (Frank 1975:DC; Turner and others 1973:HRR; Anderson 1976:HRF). Because geomyids are so adaptable in their feeding habits, plant composition and abundance are probably the primary regulators of gopher density in a habitat (Walker 1949:DT; Moore and Reid 1951:HRR; Keith and others 1959:DC; Turner and others 1973:HRR; Barnes 1974:HRF; Buchner and Rorabaugh 1979:DTF). Gopher densities usually increase on lands disturbed by fire, roadbuilding, logging, site preparation, or other events that open the canopy or disturb the soil. Preferred early successional forbs and grasses often thrive in these areas (Crouch 1969:DTF; Volland 1973:HRF; Anderson 1976:HRF; Capp 1976:DTF; Burton and Black 1978:FF), and this may increase the carrying capacity in gopher-occupied areas or may encourage the establishment of new populations (Barnes 1974:HRF).

Andersen and MacMahon (1981:RGA) studied populations of *T. talpoides* in four stages of a montane sere ranging from subalpine forb meadow to climax Engelmann spruce (*Picea engelmanii*) forest. Usable plant energy decreased with each successive stage. The availability of palatable underground vegetation correlated with the rodent populations. Climax spruce forest could not meet their year-round energy requirements, and intermediate seral stages were not likely to meet the energy needs associated with reproduction in females. In early seral stages, Andersen and MacMahon (1981:RGA) thought weather patterns that restricted burrowing efficiency influenced population growth more than the abundance of food.

Pocket gophers avoid areas with heavy brush, slash, or deep shade (Buchner and Rorabaugh 1979:DTF). Overstory removal that leads to brush encroachment and limits herbage growth also discourages gopher inhabitation (Barnes 1974:HRF). Similarly, when herbicide treatments reduce vegetation, significant reductions in gopher densities follow (Howard and Childs 1959:HRR; Keith and others 1959:DC; Hansen and Ward 1966:HRR; Tietjen and others 1967:HRR).

Population densities may not directly relate to elevation, but soil and vegetation, as they vary with altitude, influence them indirectly (Best 1973:DT; Reid 1973:RGA). Tryon and Cunningham (1968:NH) compared an alpine population of *T. talpoides* with one existing 2,200 ft (670 m) lower. Fewer animals occupied the high elevation habitat. Forage, however, was of a higher quality in the alpine zone and individuals there were larger.

Abundance

Anderson (1976:HRF) characterized *T. talpoides* populations in their Oregon habitats with 19 variables measured on 157 sites. Gopher activity and numbers caught increased with elevation and slope and in more mesic conditions. A large number of forbs in disturbed areas provided the best habitat. In Yellowstone National Park, Youmans (1979:HRF) studied populations of *T. talpoides* and relationships to vegetation, soil texture, soil moisture, and snowmelt phenology. His data suggested that soil depths and temperatures, not forb production, primarily limited gopher densities. Soil moisture limited their distribution.

Volland (1973:HRF) describes preferences of pocket gophers for certain habitat types in central Oregon. He divided 1,798,900 acres (728 000 ha) into 23 identifiable community types then consolidated the communities into three classes: moderate to high incidence of gophers; low incidence, but a great potential for occupancy; and little activity. Most preferred communities were lodgepole pine sites supporting lush stands of long-stolon sedge, forbs, or both. Gopher activity in natural nondisturbed stands was minimal or nonexistent.

Irregular and rapid fluctuations commonly occur in the rodent populations from year to year (Ingles 1952:HRR; Tietjen and others 1967:HRR; Tryon and Cunningham 1968:NH; Julander and others 1969:HRR; Andersen and MacMahon 1981:RGA). However, populations exhibit a relative degree of stability over time that is often attributed to intraspecific territorial behavior (Howard and Childs 1959:HRR; Hansen 1962:M; Vaughan 1967:DT). Andersen and MacMahon (1981:RGA) hypothesized that intraspecific competition suppressed growth in subalpine populations when they reached some threshold density. Maximum densities vary with locale (table 4), but studies show *T. talpoides*

Table 4.—*Late summer and fall pocket gopher densities by area and habitat type*

Species	Habitat	Location	Number years censused	Density (individuals/ha) Range	Max.	Mean	Source
Thomomys talpoides	Mountain meadow	Bridger Mts., Mont.	1	—	74		Tryon 1947:NH
		Beartooth Mts., Wyo. (Canadian Zone Sta.)	6	15-44	44		Tryon and Cunningham 1968:NH
		Grand Mesa, Colo.	9	20-52	52	37	Reid 1981:RGA
		Black Mesa, Colo.	15	12-79	79	52	Ibid.
		Wasatch Mts., Utah	2	67-96	96		Richens 1965:PD
		Bear River Mts., Utah	3	10-62	62		Andersen and MacMahon 1981:RGA
	Aspen-dominated forest	Utah	3	2-35	35		Ibid.
	Subalpine fir forest	Utah	3	0-10	10		Ibid.
	Engelmann spruce climax	Utah	3	0-2	2		Ibid.
	Grazed ponderosa pine bunchgrass	Colorado	7	—	—	10	Reid 1973:RGA
	Ungrazed	Colorado	7	—	—	22	Ibid.
Thomomys monticola	Mountain meadow	Sierra Nevada Mts., Calif.	4 combining data for two meadows: autumn only	10-36	36		Ingles 1952:HRR
Thomomys bottae mewa	Annual type range	California	6 year long census	49-101	101		Howard and Childs 1959:HRR
Geomys breviceps	Open pasture	Eastern Texas	1 spring counts	—	17[a]	3	Davis and others 1938:S

[a] This maximum density is based on a report they note from another study in the same area.

populations consistently peak at between 24 and 36 individuals per acre (60 to 90 per ha). (Andersen and MacMahon 1981:RGA).

Density-independent factors most likely regulate population densities below peak levels.

Longevity, Age, and Sex Structure

Andersen and MacMahon (1981:RGA) did not find fertility rates to vary with density, and attributed variation in population levels wholly to factors influencing mortality rates. Longevity varies among gophers. Maximum lifespans range from 3 to 5 years with an average close to 2 years (Ingles 1952:HRR; Reid 1973:RGA). Young-of-the-year may replace 75 percent or more of the population annually (Tryon 1947:NH; Hansen 1960:RGA; Youmans 1979:HRF).

Juvenile survivorship strongly impacts population densities (Vaughan 1967:DT). In the Pacific Northwest, juveniles comprise a greater percentage of the population in fall (Youmans 1979:HRF) while adults constitute a larger proportion in spring and summer (Tryon 1947:NH; Hansen and Ward 1966:HRR) (table 5). In Colorado, Reid (1973:RGA) found a general correlation between the age structure in fall and gopher density the following year. Increased adult body weights and high juvenile populations in fall (greater than 50 percent) usually indicated high densities the following year. Conversely, when fall populations exhibited a preponderance of adults (greater than 50 percent), abundance tended to decline the next year.

Rising ground water tables during snowmelt create the period of greatest vulnerability for young (Vaughan 1967:DT; Hansen and Reid 1973:DT). Populations showed abrupt declines when adverse snow conditions resulted in poor juvenile recruitment. Reid (1981:RGA) suggested that the water content of the snowpack and the date at which snowmelt was complete could be used to indicate population trends.

Male to female sex ratios vary in gopher populations and usually relate to the sampling season (Howard and Childs 1959:HRR). Estimates often show a preponderance of adult females to adult males, with juvenile ratios generally more balanced (Wood 1949:RGA; Hansen 1960:RGA; Lay 1978:RGA; Andersen and MacMahon 1981:RGA) (table 6).

Andersen and MacMahon (1981:RGA) hypothesized that males may experience higher mortality because of increased activity during the breeding season, resulting in prolonged exposure to wet, saturated soils. Brown (1971:RGA), studying *G. pinetis* in Florida, believed males travel aboveground to search out females for

Table 5.—*Age structure of pocket gopher populations*

Species	Number years sampled	Time of sampling	Percent adults	Percent juvenile	Total number of gophers sampled	Source
Thomomys talpoides	15	Fall		57	2,531	Reid 1981:RGA[a] (Black Mesa)
	5	Fall		64	1,083	Ibid. (Grand Mesa)
	1	June		7	69	Youmans 1979:HRF
		Aug.		78	9	
		Sept.		80	64	
	4	Year round during snow-free periods		34	1,738	Hansen 1960:RGA
	4	June		14		Tryon 1947:NH
		Aug.		55		
		Sept.		72		
Geomys pinetis	1	(Monthly May-April)				
		July	48.2		505	Brown 1971:RGA[b]
		Oct.	67.4			
		Feb.	82.4			
Geomys bursarius	3	Monthly				
		total		23	1,218	Vaughan 1962:RGA
		Aug.-Dec.		48		
		Feb.		40		
	1	Sept.		42.3	585	Wood 1949:RGA[c]
		Nov.		3.3		
		Dec.		0		

[a] Generally, young of the year dominated in fall populations and their densities often determined population sizes—particularly in years when they were near the mean high population level.
[b] Brown distinguishes 3 age classes: adults, subadults, and juveniles.
[c] This figure includes females only.

Table 6.—*Sex ratio for different populations of pocket gophers*

			Percent males				
Species	Number years censused	Time of sampling	Adult	Juvenile	Adult and juvenile combined	Number sampled	Source
Thomomys talpoides	9	July-Sept.	54.4			68	Ellison and Aldous 1952:HRR
				53.4		116	
	4	Early summer breeding season	32.3	50[a]		129	Andersen and MacMahon 1981:RGA
	4	Fall: (12-32 gophers/acre)		50	42	2,531	Reid 1981:RGA[b]
	11	Fall: (40-79 gophers/acre)		50	54		
	5	Fall		50	47	1,083	Hansen 1960:RGA
	4	Year-round during snow-free periods	47			1,157	
				43		376	
Thomomys bottae	1	April - May			37	505	Lay 1978:RGA
			26			199	
				45		406	
Geomys bursarius	1	Sept. - Aug.	40.4[c]	44.8		561	Wood 1949:RGA
	3	Monthly:			43	1,218	Vaughan 1962:RGA
		May - Aug.		51		125	
Geomys pinetis	1	Monthly:			44	505	Brown 1971:RGA
		May - April	40			339	
				51		166[d]	

[a] Sex ratios "believed" equal prior to the breeding season.

[b] Females were significantly more abundant at low population levels and males were more abundant when densities were at higher levels.

[c] This figure combines data for adults and subadults.

[d] This represents combined data for juveniles and subadults.

mating and become more susceptible to predation. Males moving farther and occupying larger territories than females may influence capture and sex ratio estimates (Howard and Childs 1959:HRR).

Lay (1978:RGA) found significantly more females than males among *T. bottae* of breeding age and suggested the existence of polygyny. Male mortality may increase if polygyny leads to increased intraspecific aggression among males competing for females. In an earlier study, Howard and Childs (1959:HRR) discussed polygyny in *T. bottae mewa* and formulated similar conclusions.

Data collected in Colorado over several years revealed more adult females than adult males present during low population years (Reid 1981:RGA). Males dominated sex ratios during high population years. Young-of-the-year demonstrated a mean sex ratio of 50:50 for all observed years.

Hansen (1960:RGA) found an abundance of males and lower susceptibility of pregnant females to trapping during the early spring. However, as indicated by capture, females comprised a greater segment of the population later in the summer. Hansen concluded that females increase their activity when engaged in postnatal care of the young and become more susceptible to trapping. Balanced sex ratios generally existed at other times of the year.

Predation

Pocket gophers fall prey to a number of avian, mammalian, and reptilian species (Hegdal and Gatz 1976:BE), but predators alone do not have a significant influence on gopher densities (Tryon 1947:NH; Howard 1953:DC; Howard and Childs 1959:HRR). Weasel (*Mustela* sp.) invasion of gopher territory may slow population growth or even contribute to a decline, but weasel impact in regulating density is thought to be minimal (Hansen and Ward 1966:HRR; Andersen and MacMahon 1981:RGA). Coyote (*Canis latrans*) predation, studied for its role in possible biological control, apparently did not influence the rodent populations (Colorado Cooperative Pocker Gopher Project 1960:DT). Other mammalian predators include ermine (*M. erminea*), foxes (*Vulpes* spp.), bobcat (*Lynx rufus*), badger (*Taxidea taxus*), skunks (*Mephitis* spp. and *Spilogale putorius*), and grizzly bear (*Ursus arctos horribilis*) (Moore and

Reid 1951:HRR; Downhower and Hall 1966:DT; Hansen and Ward 1966:HRR; Reid 1973:RGA).

Common avian predators include great horned owl (*Bubo virginianus*), red-tailed hawk (*Buteo jamaicensis*), Swainson's hawk (*B. swainsoni*), common barn-owl (*Tyto alba*), great gray owl (*Strix nebulosa*), long-eared owl (*Asio otus*), burrowing owl (*Speotyto cunicularia*), northern goshawk (*Accipiter gentilis*), and American kestrel (*Falco sparverius*) (Fitch and others 1946:PM; Tryon 1947:NH; Howard and Childs 1959:HRR; Downhower and Hall 1966:DT; Hansen and Ward 1966:HRR; Marti 1969:PM).

Noted reptilian predators include the bullsnake (*Pituophis sayi*) (Hisaw and Gloyd 1926:PM), gopher snake (*P. melanoleucus*), and rattlesnake (*Crotalus* spp.), but other species may also take gophers (Reid 1973:RGA).

Parasites

Although pocket gophers host numerous species of internal and external parasites, there is little concern to public health, and infestation does not generally affect gopher population levels (Tryon 1947:NH; Reid 1973:RGA).

Ectoparasites include mites and ticks (*Acarina*), lice (*Mallophaga*), and fleas (*Siphonaptera*) (Miller and Ward 1960:PD; Price 1972:PD; Tuszynski and Whitaker 1972:PD; Rust 1973:PD). The degree varies to which estoparasites show host-specificity to pocket gophers (Miller and Ward 1960:PD). Because these rodents lead relatively solitary lives in subterranean environments, transfer of ectoparasites to other animals is minimized. Characteristics of gopher molt and grooming behavior may further restrict parasitic distribution (Rust 1973:PD).

Internal parasites include roundworms (*Nematoda*), tapeworms (*Cestoda*), and some protozoa (Tryon 1947:NH; Todd and Lepp 1971:PD). Liver parasites (*Capillaria hepatica*), most often prevalent in high density gopher populations, can cause significant atrophy of the liver (Tryon 1947:NH; Tryon and Cunningham 1968:NH).

POPULATION ESTIMATION

Surface Sign

Investigators use surface signs such as mounds, earth plugs, and soil casts as indices to gopher burrowing activity and abundance (Miller and Bond 1960:B; Richens 1965:DC; Reid and others 1966:PE) (fig. 5). Numbers of fresh mounds per acre (hectare) or per mile (kilometer) of transect can denote relative abundance of the animals on a unit area (Phillips 1936:HRR; Mohr and Mohr 1936:B; Julander and others 1959:HRR; Hansen and Ward 1966:HRR). Mound counts can also indicate damage potential on a site and the necessity for control efforts.

Beck and Hansen (1966:PE) detailed a method of expressing gopher abundance based on frequency of mounds along transects. Richens (1965:DC) derived an index to population density based on a simple program of trapping and mound counts. High correlations existed between gopher density and the number of fresh mounds observed bimonthly throughout the summer. Cumulative mound counts made annually in early August also correlated with gopher abundance. A poor relationship existed between population levels and mounds constructed in short 72-hour periods. Reid and others (1966:PE), however, found a significant correlation between numbers of pocket gophers and the number of fresh mounds and earth plugs appearing on sample plots in 48-hour periods. All mounds and earth plugs on sample plots were initially erased by flattening, then 48 hours later all new mounds and plugs were counted. Immediately after this, each plot and 20 ft (6 m) of surrounding buffer zone were saturated with kill traps to

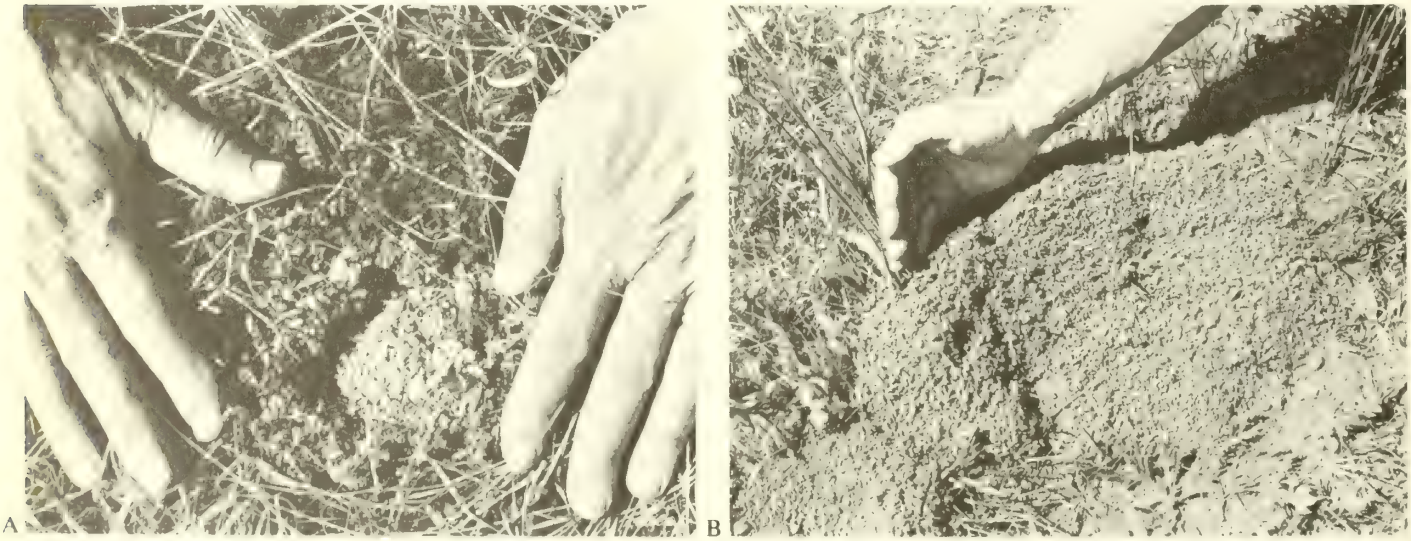

Figure 5.—(A) Earth plugs are one of the surface signs of gopher activity. (B) Fresh mounds can be observed during the summer and fall.

determine the number of active pocket gophers present. It is important to determine this animal-to-sign relationship for each different area because the amount of surface sign per gopher may vary with time of year, herbage composition, and gopher species. Sample plots trapped should encompass the burrow systems of several animals. Sign counting to inventory pocket gophers should take place after young-of-the-year disperse and establish burrow systems, usually in late summer and early fall. In Montana, Youmans (1979:HRF) placed limited value on mound counts to census gophers prior to late July. The advantages of sign counting include minimum site disturbance, rapid analysis, and relatively few worker-hour requirements (Reid 1973:RGA).

Trap-Outs

Trap-out techniques arrive at population counts more directly by attempting to capture all animals on a unit (Ingles and others 1949:PE; Howard and Childs 1959:HRR; Richens 1965:DC). Fall trapping produces the most accurate estimates after young attain trappable size (Reid 1981:RGA). The advantages of this technique include count accuracy and rodent availability for immediate examination (Reid 1973:RGA).

Winter Soil Casts

Winter soil casts evident after snowmelt may provide an index to populations prior to reproduction in early summer (Richens 1965:DC; Reid and others 1966:PE; Reid 1981:RGA) (fig. 6). Youmans (1979:HRF), however, reported soil casts represented summer and fall populations the previous year but did not indicate current spring densities. Erroneous population estimates can result from soil cast indices because winter activity depends on the initial winter population, overwinter survival, duration of continuous snow cover, and the presence of frozen soil beneath the snowpack (Reid 1973:RGA).

Open Hole

The open hole technique is used to express relative population abundance or to evaluate postcontrol treatment success (Miller and Howard 1951:DC; Richens 1968:DC; Barnes and others 1970:DC; Birch 1978:DC). Certain behavioral traits of gophers form the basis for this method's use. The method relies on gophers' solitary habits and on their general tendency to plug holes in burrow systems within 24 hours. Personnel open

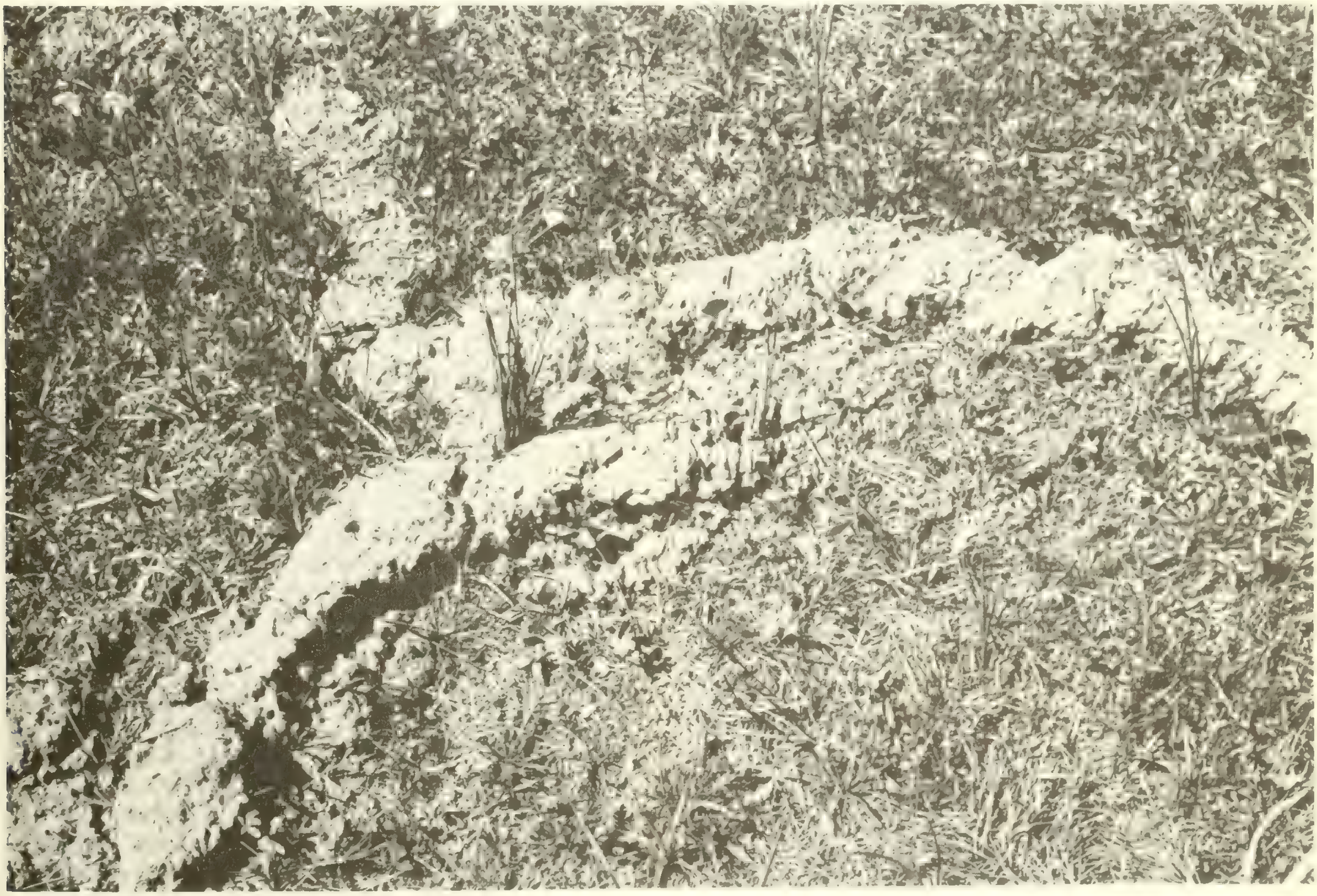

Figure 6.—Winter casts often remain intact for several weeks after the snow melts.

marked burrows, then check the number of replugged holes 24 hours later for indications of activity. Control treatment evaluation involves using this survey in establishing pretreatment activity levels, treating burrow systems with some control agent, and then repeating the survey 7 to 14 days later. Reopened holes left unplugged 24 hours after this followup survey probably indicate a dead gopher. Rainy periods may invalidate this technique because gophers may not plug holes when relative humidity at ground level reaches 94 percent or more (Hungerford 1976:FF). Plural occupancy may result in conservative density estimates (Miller 1953:DC; Richens 1968:DC).

Aerial Photography

Low or sparse vegetative cover permits the use of 1:600 and 1:1,200, large-scale, normal color, or infared aerial photography to make mound counts. Accuracy of this method compares favorably (97 percent) with ground count estimates (Driscoll and Watson 1974:PE).

Trapping Transects

Animals trapped along transect lines provide relative abundance estimates (Keith and others 1959:DC; Hansen and Ward 1966:HRR; Tietjen and others 1967:HRR). Personnel locate tunnels by probing at 3- to 4-inch (8- to 10-cm) intervals along predetermined lengths of transects, then set traps within the tunnels. Captured animals provide an index to area population, and specimens are readily available for life-history studies.

Capture-recapture techniques employ marking live-trapped animals with either metal bands or by toe-clipping on the hind foot (Ingles and others 1949:PE; Andersen and MacMahon 1981:RGA). This technique requires many hours of trapping, but it also provides good information on survivorship and on other characteristics for demographic analysis.

Nearest Neighbor

A Colorado range study used the "nearest neighbor" concept to estimate gopher population densities and to determine the relationship of density to territory size (Hansen and Remmenga 1961:F). The method correlated the number of gophers per acre with the average distance to the nearest four captures. The average distance between catches decreased as density increased. Method results appear similar to those of simple trap-outs. Assumed random distribution can bias this method because populations may exhibit uniform or clumped distributions.

DAMAGE

For many years land managers have recognized pocket gophers as damaging pests. Gophers have been reported to gnaw underground electric cables (Howard 1953:DBM), but vegetation damage is the major problem. *Thomomys*, the most widely distributed genus in the United States, causes the majority of resource damage and economic loss. Six species of *Thomomys* occur in the Pacific Northwest. Among these *T. talpoides* and the nearly identical *T. mazama* range the widest (Ingles 1965:DT). These two species cause the majority of conifer damage in commercial forest plantations (Capp 1976:DTF).

Agricultural Lands

Agriculturalists first recognized the significance of gopher problems in many root, fruit, and bulb crops (Lantz 1918:DTR; Crouch 1933:DC). Early literature documented canal breaks costing thousands of dollars in crop losses and repairs because of gopher burrowing activities in the banks (Day 1931:S; Scheffer 1931:B; Downhower and Hall 1966:DT). Periodic flooding of cropland often discourages rodent populations, but nonirrigated crops may become particularly susceptible to gopher inhabitation (Scheffer 1931:B). *Thomomys quadratus* caused serious root damage and significant economic loss in Oregon orchards (Wight 1930:RGA). In addition, vast numbers of gopher mounds and dirt heaps on a field can cover large areas of growing crops and later obstruct harvesting operations. As many as 1,200 to 1,500 mounds per acre (3 000 to 3 700 per ha) may occur on a field of average infestation (Scheffer 1931:B).

Rangelands

The abundance of gophers on rangelands can drastically reduce ground cover and herbage production as a result of burrowing, mound building, and foraging (Turner 1973:HRR). Mounds and castings can cover 4 to 10 percent of the ground area (Buechner 1942:HRR; Ellison 1946:S). Where gopher densities are particularly high, displaced soil may cover up to one-fourth of the surface area within 1 year (Turner 1973:HRR). Food availability often determines the foraging range of individual animals. Digging activity and soil disturbances may increase on poor range where a gopher will extend its burrow system in search of more vegetation (Scheffer 1931:B; Moore and Reid 1951:HRR).

Pocket gophers harvest and bury large quantities of vegetation during foraging activities and can greatly influence plant composition and density. On a range in Texas, Buechner (1942:HRR) found that gophers brought more than 5,600 lb/acre (6 300 kg/ha) per year to the surface and covered over 8 percent of the vegetation annually. A Colorado study revealed that gophers reduced the available herbage by as much as 20 percent or almost 80 lb/acre (90 kg/ha) (Turner 1969:HRR; Turner 1973:HRR). Andersen and MacMahon (1981:RGA) concluded that *T. talpoides* in Utah consumed 30 percent or more of the net annual primary production allocated to belowground plant parts. In Utah, Richens (1965:DC) found that areas under gopher control treatment produced two to three times more plant tissue than nearby uncontrolled areas.

Feeding activities and soil disturbance subject various plant species to different selective pressures (Buechner 1942:HRR). High gopher densities generally suppress perennial forbs and grass species even though annual weeds and grasses continue to thrive (Moore and Reid 1951:HRR; Turner 1969:HRR; Laycock and Richardson

1975:HRR). Some plants such as slender wheatgrass (*Agropyron trachycaulum*) and mountain brome (*Bromus carinatus*) may respond favorably to pocket gopher activity and benefit livestock (Turner 1973:HRR). Other potentially harmful plants such as orange sneezeweed (*Helenium hoopesii*), a species poisonous to sheep and unpalatable to cattle, may increase as a result of gopher activity (Turner 1969:HRR).

The degree of gopher influence on herbage composition depends on soil and vegetation characteristics and livestock grazing intensity over time (Moore and Reid 1951:HRR; Turner 1969:HRR). Buechner (1942:HRR) found gophers most abundant on overgrazed ranges and on heavily used areas where vegetation remained in early successional stages.

Gopher activity can aggravate impacts of grazing livestock and further contribute to range deterioration. Burrowing and mound building prevented the return of fescue (*Festuca idahoensis*) in Utah cattle enclosures (Tevis 1956:DTF). Moore and Reid (1951:HRR) found that gophers prevented perennial grasses from reestablishing on overgrazed ranges in Oregon. They also noted that overgrazing on poor range required gopher control for range improvement, but thought that control probably was unnecessary for meadows in fair condition.

Alternatively, in Kansas the plains pocket gopher destroyed undesirable weeds by feeding and digging (Downhower and Hall 1966:DT). Hall (1955:GR) discussed how gophers might actually improve conditions for grass return on overgrazed ranges. In the absence of livestock grazing, gophers destroyed large-rooted weeds and enabled grass reestablishment. Decreases in gopher abundance might result from the improvement of range conditions and the exclusion of livestock grazing. Similarly, on the subalpine grasslands in Utah, Ellison and Aldous (1952:HRR) found that grasses and sedges increased in the presence of gophers and the absence of cattle.

Gopher digging activities may affect development of rangeland soil (Grinnell 1923:S; Turner 1973:HRR). The rodents constantly mix earth during excavation activities. Richens (1966:B) estimated that they displaced 30,000 lb soil per acre (34 000 kg/ha) on mountain rangeland each year. Gophers may enhance range productivity by loosening and softening heavy clay soils previously compacted by livestock (Ellison and Aldous 1952:HRR; Ratliff and Westfall 1971:S). They may render ground more fertile through disturbance if minerals, interstitial air, and water become more available to plants (Grinnell 1923:S; Downhower and Hall 1966:DT). Tevis (1956:DTF) reported that gopher digging on overgrazed ranges in Utah left bare mineral soil exposed, creating an ideal seedbed for conifers. However, he noted later that gophers were destructive to seedlings trying to establish on the range.

The increased permeability and porosity of soil caused by this rodent's activity may favor water conservation (Turner 1973:HRR). Conversely, burrowing may cause accelerated soil erosion through the formation of erosion gullies (Tevis 1956:DTF). The soil piled on the surface weathers sooner and may contribute to increased sediment load in the watershed (Frank and others 1975:S). Free-flowing water channeled by castings can initiate erosion scar formation, and water flow through burrows can hasten soil breakdown (Day 1931:S). Marston and Julander (1961:HRF) found that pocket gophers reduced perennial plant cover in an aspen-cleared plot in Utah. They thought the remaining ground cover would not provide sufficient protection to the soil from overland flow and might enhance erosion.

Gopher influence depends on characteristics of individual areas and the intensity of land use. Ellison (1946:S) reported that gophers on the Wasatch Plateau in Utah helped to accelerate erosion, but overgrazing by cattle on the range caused the majority of the problems.

Forest Lands

On forest lands, intensified reforestation efforts throughout the West reveal that gophers can seriously hinder successful seedling regeneration (Moore 1940:DTF; Dingle 1956:DTF; Hermann and Thomas 1963:HRF; Barnes and others 1970:DC; Hooven 1971:DTF).

Gophers destroyed two-thirds of the trees on study plots in Oregon's 15,000-acre (6 100-ha) Cave Mountain burn within 3.5 years (Crouch 1971:DTF). Damage resulted in the loss of the $200,000 planting cost and an estimated loss of 450,000 bd.ft. ($9,000) (Canutt 1970:DTF). On the smaller, 170-acre (69-ha) Dugout Lake burn, pocket gopher depredation basically eliminated stocking (Barnes 1973:DTF). Damage control after replanting the area in 1969 included two $3,500 gopher-baiting programs. Costs reached $19,000 as of 1973 for both plantings and damage control.

Pocket gopher damage currently affects at least 300,000 acres (121 000 ha) of USDA Forest Service lands (Barnes 1978:DC), and rates as a major forest animal pest. Most damage is reported on ponderosa pine (*P. ponderosa*) plantations (Dingle 1956:DTF; Crouch 1969:DTF; Hooven 1971:DTF; Barnes 1973:DTF; Barnes 1974:HRF).

The response of populations resulting from forestation practices will vary between habitat types and with silvicultural practices. Clearcuts may support large populations, and damage often is acute in these areas (Williamson and Minore 1978:DTF; Minore 1978:DTF). Barnes (1974:HRF) found pocket gophers less abundant but widely distributed through shelterwood cut areas. Delayed reforestation after harvest poses the most serious problem through creation of open disturbed areas. These areas provide ideal gopher habitat, and as populations build with the establishment of profuse vegetation, the problems of reforestation increase (Barnes 1974:HRF; Capp 1976:DTF; U.S. Department of Agriculture 1979:DC). Pocket gopher problems will probably increase in all conifer stands, although future problems will intensify in true fir stands (Borrecco 1982, personal communication) and lodgepole pine (*P. contorta*) because of increased logging activity (U.S. Department of Agriculture 1979:DC). Some of the most serious impacts to reforestation take place when gophers, deer, elk, cattle, or beaver impact areas simultaneously (Evans and others 1981:DTF).

Identification and Description

Conifer damage by pocket gophers results from root pruning, stem clipping, girdling, partial removal of stems and crowns, or total removal of small seedlings (Barnes 1973:DTF) (fig. 7). Gophers can seriously affect conifer regeneration up to 10 years after planting (Dingle 1956:DTF). The most serious damage, however, occurs within the first 2 or 3 years, and damage to small seedlings often results in mortality (Crouch 1971:DTF; Hooven 1971:DTF). Crouch (1971:DTF) reported that total seedling removal caused 76 percent of the tree loss in the Cave Mountain, Oreg., burn study area.

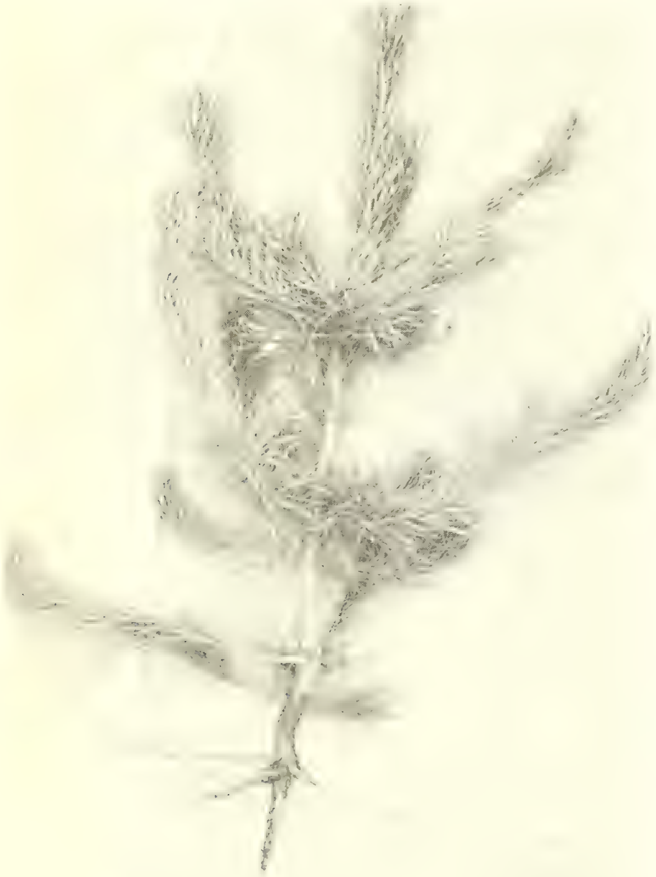

Figure 7.—The root system of an established seedling is nearly destroyed by the pocket gopher.

Extensive gopher damage to conifer seedlings most commonly occurs in the absence of preferred vegetation (Burton and Black 1978:FF). Damage to trees occurs year-round but most frequently in winter. Scarcity of herbaceous vegetation forces gophers to feed above ground beneath the snowpack (Crouch 1969:DTF, 1979:DC; Canutt 1970:DTF; Barnes 1973:DTF; Buchner and Rorabaugh 1979:DTF). Barnes (1974:HRF) found that 90 percent of the gopher-caused tree damage on his study area occurred in winter with virtually all damaged trees dying. Allen and others (1978:DC) found gopher damage greatest during winter on the Targhee National Forest, with the majority attributed to crown clipping. Tree girdling occurred beneath the snowpack to a height of 3.3 to 3.9 ft (1 to 1.2 m). Hooven (1971:DTF) observed girdling damage in lodgepole pine to a height of over 7 ft (2.1 m). Extensive winter damage results in obvious white tree trunks showing after snowmelt (Barnes 1973:DTF).

Teeth marks on trees and shrubs characterize pocket gopher damage. Winter soil casts, mounds, or runways occasionally surround injured trees. Removal of a young seedling may result in a mound or plug or in no visible sign at all (Canutt 1970:DTF).

Porcupines (*Erethizon dorsatum*) or mountain beaver (*Aplodontia rufa*) were blamed for some pocket gopher damage in the past (Crouch 1969:DTF). Porcupines generally limit barking to the outer wood surface, while gophers often gnaw deeply into the wood of old seedlings and young saplings (Canutt 1970:DTF) (fig. 8). In addition, porcupines leave discarded fragments of outer bark at the base of the damaged tree while gophers do not.

Evidence of root pruning may not become apparent until the tree shows visible signs of stress. Trees may tilt and foliage may turn brown over time (Canutt 1970:DTF).

Tevis (1956:DTF) reported that burrowing gophers left the roots of red fir seedlings exposed with extensive damage resulting. However, Barnes (1973:DTF) and Turner (1973:HRR) thought that root exposure and damage resulting from burial by mounds and winter casts constituted lesser forms of injury.

CONTROL

The task of computing an economic analysis of pocket gopher damage and control remains difficult. Lack of data and detailed damage surveys creates a problem in estimating the extent of actual gopher impact on managed lands. Limited funding and a need to prioritize control areas complicate management decisions.

Presently, economic concern is primarily on gopher impacts to harvestable forest lands. Growing demands for wood products and subsequent inflation of timber values provide the basis for this concern.

Increased concern by land managers led to the formation in 1973 of the Northwest Forest Pocket Gopher Committee (NWFPGC) to study damage problems and promote solutions. In 1974, this group affiliated with the Oregon-Washington Silvicultural Council of the Western Forestry and Conservation Association. In 1975, the committee developed a questionnaire designed to determine the extent of gopher damage in the Pacific Northwest and the efforts to control it. Results of this survey showed that the majority of damage occurred on forest lands east of the Cascade Crest in Oregon and Washington. Almost 80 percent of those surveyed thought that damage over the coming 10 years (1975 to 1985) would remain constant or increase. The group indicated that control measures involved only 10 percent

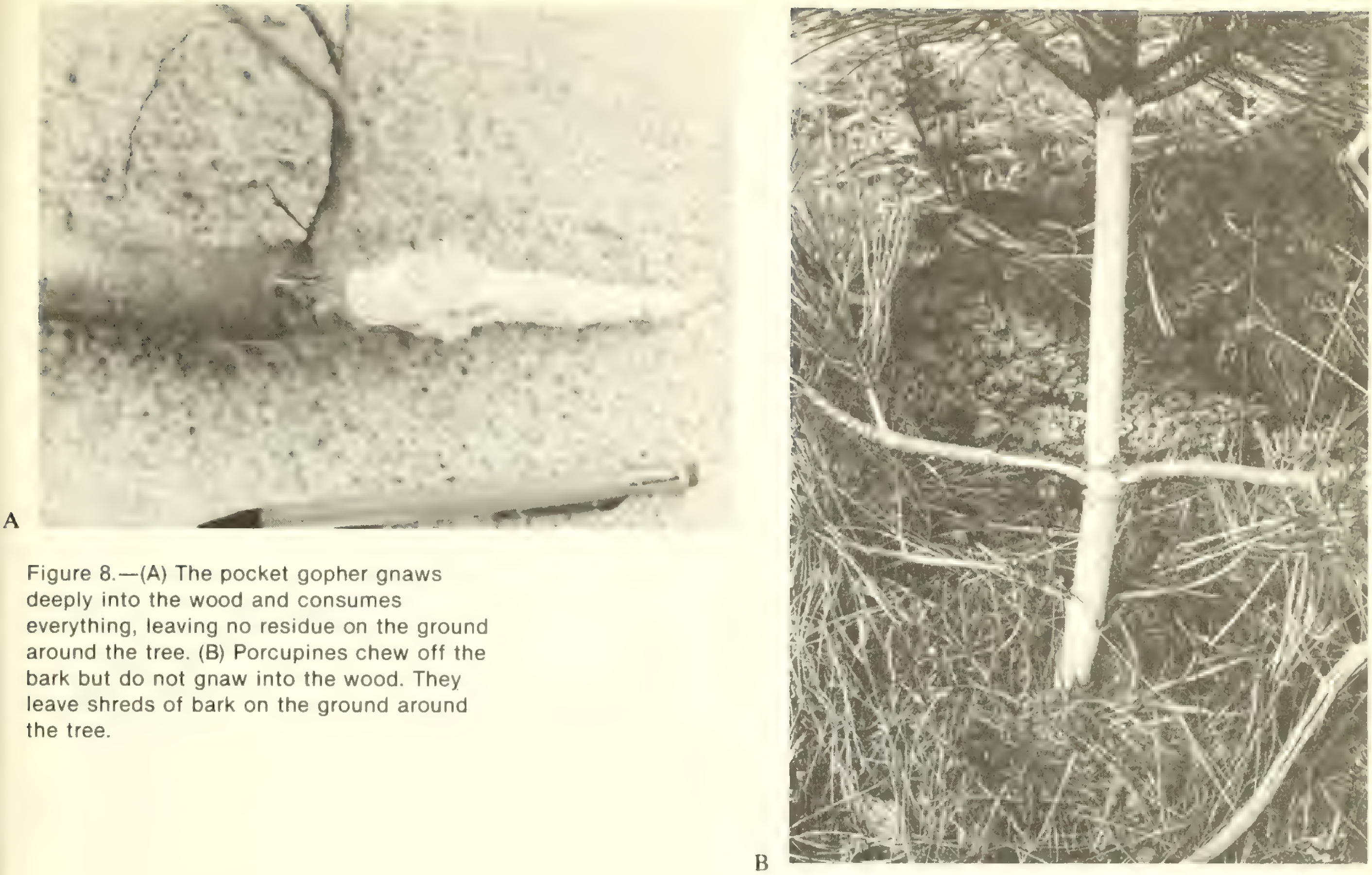

Figure 8.—(A) The pocket gopher gnaws deeply into the wood and consumes everything, leaving no residue on the ground around the tree. (B) Porcupines chew off the bark but do not gnaw into the wood. They leave shreds of bark on the ground around the tree.

of the gopher-affected acreage; 80 percent of those administering control programs thought their efforts insufficient. Factors contributing to poor success included inadequate budget, personnel, equipment, and control techniques, and the inability to detect damage.

A recently formed USDA Forest Service "activity review team" looked at gopher-reforestation issues to find more workable solutions (U.S. Department of Agriculture 1979:DC). Under the team's influence, western Forest Service Regions 4 and 6 compiled available data on total area planted, seedling survival, area subjected to gopher control, and all associated costs for these programs. This type of comprehensive review in each region could serve as a starting point.

On forest lands control difficulties intensify when managers fail to anticipate damage while planning timber harvest (Barnes 1974:HRF; Buchner and Rorabaugh 1979:DTF). Early recognition of potential problem areas and prompt application of direct or indirect control could prevent or reduce losses (Barnes 1973:DTF; Capp 1976:DTF; Buchner and Rorabaugh 1979:DTF). Conifer losses in some areas may gradually increase enough to cause reforestation failures or restocking delays. Managers should monitor suspected problem areas and determine the need for damage control annually (Crouch 1979:DC). Cooperation among land managers, including wildlife biologists, will help prevent or decrease animal damage conflicts (Capp 1976:DTF; U.S. Department of Agriculture 1979:DC). Kinds of control vary with area size and situation. Successful control must exceed the naturally high annual gopher mortality rates (70–75 percent) (Hansen 1960:RGA). Capp (1976:DTF) recommends a population reduction of 90 percent. Managers must become familiar with the advantages and disadvantages of techniques. On rangelands, studies document both positive and negative influences of burrowing gophers, but the necessity for control efforts often remains unclear. Where they are integral components of range communities, the gophers' influence on habitat is difficult to evaluate apart from other interacting segments of the ecosystem. Personnel need to define the relationships between the amounts of forage consumed by gophers and the costs of control. In addition, factors that tend to naturally control or minimize the impact of damage need consideration. Gophers are less frequently a problem on well-managed rangelands. Control is more commonly recommended for improvement of deteriorated range than for maintenance of range in fair or good condition (Tietjen 1973:DC).

Alsager (1977:HRR) outlined a method for determining rodent impact to net vegetation production, and for analyzing costs and benefits of control. The technique requires intense labor effort but may warrant further evaluation.

Cost

The Pocket Gopher Reforestation Activity Review Team reported that the cost of contracting for rodent control doubled in the past few years (U.S. Department of Agriculture 1979:DC). Birch (1982, personal communication) concluded from a 1977 study that a 1.69:1 cost-benefit ratio existed on the Ashton Ranger District, Targhee National Forest, Idaho. Subsequent contract bidding competition reduced the cost of treatment. Present treatment costs range from $20 to $25 per acre ($50 to $62 per ha) for 2 years of treatment after planting, to $40 per acre ($100 per ha) for 7 years of protection. Birch (1978:DC) prepared guidelines for organizations wishing to initiate contract baiting control. Costs often increase because seedlings may remain vulnerable to gopher depradation up to 10 years, and many require treatment throughout this period. As reforestation efforts increase to meet expanding demands for wood products, gopher depradation and economic impacts can be expected to intensify (Capp 1976:DTF).

Methods

1. Poison baits.—Poison-coated baits constitute the most commonly used method of gopher population reduction. Baits used with good success include grains such as whole wheat, oat groats, milo, hulled barley, and cracked corn (Marsh and Cummings 1976:DC). In laboratory feeding tests *Thomomys* sp. accepted oat groats and soft milo maize more readily than other grain. Gophers preferred fresh carrots over other vegetables (Ward 1973:FF). Hungerford (1976:FF) found that gophers locate food by odor, and of the food odors tested, fresh carrot juice elicted the most obvious response.

Managers most commonly use strychnine alkaloid poison to coat baits (Capp 1976:DTF; Marsh and Cummings 1976:DC). The poison is fast acting and generally provides excellent control. Success of strychnine alkaloid as a poison depends on consumption of a lethal dose within a short time (Copeman 1957:DC). Animals ingesting sublethal doses may develop a bait aversion instead of dying (Marsh and Cummings 1976:DC). Reasons for consumption of sublethal quantities of poison include: preferences and availability of natural foods in comparison with baits, reduced toxicity of cached bait, and varying levels of bait tolerance by individuals (Barnes, personal communication). Age and associated behavior affect laboratory rodents' susceptibility to various baits (Salmon and Marsh 1979:DC). Although such studies have not been conducted on gophers, these findings may apply.

The amount of bait used varies with local conditions. A high-level strychnine bait (2.8 or 3 percent) used with the burrow builder consistently provides good control (85-95 percent or greater) under a variety of conditions and soil types. High-level strychnine baits are not recommended in hand-baiting because of the poison's hazardous nature (Marsh and Cummings 1976:DC).

Varying State and local laws govern the use of strychnine alkaloid or other toxicants for pocket gopher control. Program restrictions may limit the effectiveness of present poisoning methods (Barnes 1973:DTF; Capp 1976:DTF; Working Group of the Northwest Forest Pocket Gopher Committee 1976:DTF).

Rodenticide use and possible primary and secondary effects on nontarget species of wildlife generate substantial public concern. Possible baiting hazards to threatened or endangered species influence efforts to control damage. Studies generally indicate minimal danger to other animals from strychnine used in pocket gopher control. Fagerstone and others (1980:BE) found some evidence of nontarget strychnine mortality but no significant adverse effects on population levels. They observed little use of gopher burrows by other species.

Artificial burrow construction may result in exposure of small mammals to bait (Fagerstone and others 1980:BE). Hegdal and Gatz (1976:BE) found that bait applied with a burrow builder significantly decreased nontarget rodent populations on treated areas. Secondary strychnine poisoning might occur if predators consumed bait-killed pocket gophers or their food caches and ingested toxic doses of poison. Chances of this occurring are remote because poisoned gophers tend to die underground (Hegdal and Gatz 1976:BE; Barnes 1981, personal communications). Food caches generally contain greater concentrations of toxin than carcasses, but are less accessible because gophers often store food more than 12 inches (30 cm) below the ground surface. Hedgal and Gatz (1976:BE) concluded that proper strychnine baiting with the burrow builder did not constitute a hazard to seed-eating birds, raptors, and mammalian predators.

The development of increasingly safe and effective baits is becoming more complicated and expensive because of rigid regulations (Marsh and Cummings 1976:DC). In the future, it may be necessary to steer away from heavy reliance on poisons for control. Buchner and Rorabaugh (1979:DTF) suggest integrated pest management as an alternative.

2. Hand baiting.—Hand baiting remains as one of the oldest control methods in common use (Crouch 1933:DC; Crouch 1942:DC; Moore and Reid 1951:HRR; Colorado Cooperative Pocket Gopher Project 1960:DT). The procedure involves locating an occupied burrow system by observing mounds or plugs, finding a main runway by probing, placing toxic bait in the runway with a spoon or mechanical bait dispenser, and covering the opening.

Success depends primarily on the ability to accurately locate burrows and properly insert bait (Buchner and Rorabaugh 1979:DTF). Birch (1982, personal communication) reported that mechanical bait dispensers did not work on the Ashton Ranger District of Idaho because certain soils plugged the apparatus and personnel were unable to tell if bait was applied when the set was made. Crew morale and efficiency depend on weather, gopher activity, and the size of the treatment area. Crews of seven people working under contract may treat up to 90 acres (36 ha) per day depending on their previous experience and on the locale. Incentive pay programs may also serve to improve crew performance (Birch 1978:DC).

Costs of hand baiting relate to crew size and experience, gopher densities, topography, ground cover and debris, and travel distance (Canutt 1970:DC).

Barnes (1973:DTF) noted that baiting by hand or with a mechanical dispenser applies best to small areas or where isolated gopher populations exist. He also indicated that control efficiency dropped in areas greater than 5 acres (2 ha). Birch (1982, personal communication), however, indicated that such a drop in efficiency would be unlikely with contract baiting crews.

3. **Burrow builder.**—The burrow builder, first developed in California (Kepner and others 1962:DC) and Colorado (Ward and Hansen 1960:DC), provides one of the most efficient means for control on suitable sites (Barnes 1974:HRF; Marsh and Cummings 1976:DC). A tractor-drawn machine pulled across the ground constructs a burrow by means of a torpedo attachment and deposits bait simultaneously. The bait applicator can be used in established pastures, alfalfa and other forage crop fields, vineyards, orchards, or open fields (Marsh and Cummings 1976:DC). Some range and forest lands require the use of a sturdier version of the model (Canutt 1969:DC, 1970:DC; Barnes and others 1970:DC; Barnes 1974:HRF). On the Targhee National Forest, burrow builders constructed by Ghormley Mechanical Industries of Ashton, Idaho, and by Schneid-Miller Industries of Fort Collins, Colo., are currently in use. Birch (1978:DC), who described adjustments made to these machines and to their carriers, reported that a 1977 summer trial with a modified machine demonstrated acceptable burrow construction in rocky soils, brush, sod, slash piles, debris, and on steep slopes. The machine successfully constructed burrows in sod frozen to a depth of 1 to 2 inches (2 to 5 cm). Burrow builders, however, achieve highest success on reasonably firm, moist soils. Artificial burrows will collapse in overdry soils, and saturated soils tend to interfere with proper machine functioning (Marsh and Cummings 1976:DC).

4. **Habitat manipulation.**—Land use practices that alter habitat can strongly influence gopher populations. Range or forest management that disturbs soil and/or stimulates the production of herbaceous vegetation often improves habitat for pocket gophers. Early management planning assessment of potential gopher damage may enable effective, coordinated habitat manipulation as part of reforestation or other management goals (Volland 1973:HRF; Barnes 1974:HRF). Volland (1973:HRF) described the relationships between numerous community types and gopher densities in central Oregon, and suggested tree harvest methods and preventative management practices to minimize damage in different plant communities.

Modification of site preparation and logging practices in reforestation may discourage the establishment of favorable gopher habitat. In some cases, limiting site preparation to individual planting sites rather than disturbing entire areas will minimize soil disturbance. Barnes (1974:HRF) thought his method practical in brush fields, although problems with other animals such as rabbits and hares may increase. In some cases, however, minimal soil mixing may inhibit adequate natural restocking, or competition between pine, browse, and grass species may make it impractical (Buchner and Rorabaugh 1979:DTF). Packer (1971:DC) described other techniques of site preparation to minimize soil disturbance, including the clearing of tractor-cut strips and methods of terracing. The cutting of strips, however, may not reduce gopher damage problems, and in some cases may even increase them (Anderson 1982, personal communication).

Uncut buffer strips, 500 to 700 ft (152 to 213 m) wide, adjacent to logged areas, may delay or minimize gopher invasion from neighboring sites (Barnes 1974:HRF). Buffer strips of this size become impractical as acreage occupied by gophers increases and the value of wood products rises (Capp 1976:DTF). In addition, Crouch (1982, personal communication) observed pocket gophers traveling more than 500 ft (152 m) on logging roads between adjacent clearcuts. Thus, invasion may occur regardless of buffer strips.

Timber harvest should be designed for minimal canopy disturbance (Capp 1976:DTF). Barnes (1974:HRF) reviewed several studies indicating that the reduction in overstory canopy stimulated production of preferred gopher vegetation. He suggested that partial cuts should replace clearcutting whenever feasible. Shelterwood cuttings in lodgepole pine and mixed conifer habitat on the Deschutes National Forest, Oreg., showed promise for avoiding some of the regeneration problems experienced on wildfire and clearcut areas (Barnes 1978:DC). On the Dead Indian Plateau, Oreg., the best natural regeneration occurred when 60 percent of the overstory canopy remained after planting. Personnel estimated this optimal percentage given other variables affecting regeneration, but pocket gopher damage constituted a major concern. Buchner and Rorabaugh (1979:DTF), examining a number of harvest methods, indicated that properly employed selective cuts might result in excellent natural regeneration to the extent that gopher depredation would not cause a substantial impact.

Replanting should occur as soon as possible after harvest. Planting more and larger fast-growing stock can minimize seedling susceptibility to mortality from gophers. In addition, sites can be prepared for machine baiting by manipulating debris and planting trees to allow spaces large enough to accommodate a burrow builder (Capp 1976:DTF).

Herbicide reduces a habitat's carrying capacity for gophers by altering the plant community composition. On rangeland, treatment with 2,4-D provided dramatic reductions in forb species, and subsequent decreases in gopher populations followed (Keith and others 1959:DC; Hansen and Ward 1966:HRR; Tietjen 1973:DC; Hull 1971:DC). Extensive feeding trials revealed that direct ingestion of 2,4-D sprayed on grasses and forbs resulted in no apparent toxic effects to gophers (Tietjen and others 1967:HRR).

In forest environments, complete control of vegetation with atrazine, simazine, and 2,4-D reduced gopher activity to one-tenth of that on untreated areas. In addition, competition with conifer seedlings for soil moisture was reduced and seedling survival increased (Black and Hooven 1977:DC). Crouch and Hafenstein (1977:DC) found that aerial applications of atrazine improved survival of ponderosa pines that were subjected to competition from herbaceous vegetation and depredation by pocket gophers. Crouch (1979:DC) found in south-central Oregon that one or two fall applications of atrazine to 1-acre (0.4-ha) plots of ponderosa pine significantly increased seedling survival and growth after 10 growing seasons. His results strongly indicated that atrazine treatments over larger areas would further increase effectiveness.

Pocket gopher populations generally do not decline in response to vegetation alterations for at least 1 year after control treatments. Managers should delay forest regeneration attempts accordingly; otherwise, gophers are likely to increase feeding activity on planted conifers as other foods become unavailable (Black and Hooven 1974:HRF, 1977:DC; Burton and Black 1978:FF; Crouch 1979:DC).

Because control via vegetation alteration is short-lived, manipulation will probably be most valuable when used to improve the efficacy of direct control or to establish physical barriers to gopher dispersal. In USDA Forest Service Region 5, integrated control approaches combining habitat manipulation with baiting programs commonly occur. Baiting with increased stocking levels has also been used to resolve gopher damage problems. Combining methods of control may be expensive but necessary in many areas (Minore 1978:DTF). Because of growing concerns of potential human and environmental hazards, future use of herbicides and poison baits may be severely restricted.

5. **Kill trapping.**—Managers use kill trapping most extensively in small affected areas or where very low gopher populations occur. Trapping adequately substitutes for poisoning in terms of effectiveness, but the technique is more labor intensive and expensive (Crouch 1979:DC). Frank (1975:DC) did not consider kill trapping the most humane way of killing animals. Managers use trapping, in conjunction with other control methods, to remove any of the rodents missed in the initial control operation, to stop reinvasion at the onset, or as a research tool (Tietjen 1973:DC). Trapping incurs some nontarget mortality, but does not significantly affect other small mammal populations (Frank 1975:DC).

Of the variety of traps used, Tietjen (1973:DC) reported the Macabee type worked best for northern pocket gophers. In southern Alberta, Alsager (1977:HRR) evaluated a number of traps and achieved best success with the Guardian gopher trap. Frank (1975:DC) prepared a set of guidelines for conducting a trapping program.

Various authors discuss trapping techniques and related success (Dixon 1922:DC; Crouch 1933:DC; Storer 1938:DC). Because of characteristic behaviors of gophers, there is some controversy over whether to close openings above sets or to leave them open, exposed to light and air. Gamboa (1975:BE) tested the efficiency of both trapping methods and found no significant difference between them. He warned, however, that trapping efficiency may reflect species-specific behavioral responses.

6. **Wire caging and plastic seedling protectors.**—In the past, managers protected young trees from gopher damage by enclosing individual seedlings in wire cages. On the Dead Indian Plateau, Oreg., caged seedlings grew better in some instances than bare-root and container-grown seedlings. The cages provided protection from snow, litter fall, and foraging animals (Williamson and Minore 1978:DTF). However, managers did not consider caging practical because of expense. Industry subsequently developed plastic mesh seedling protectors such as "Vexar" to replace wire caging (Campbell and Evans 1975:DC) (fig. 9). Vexar effectively reduced gopher damage to conifer seedlings over unprotected seedlings (Anthony and others 1978:DC). In 1977, two 20-acre (8.1-ha) plots were planted with Vexar-protected seedlings on the Ashton Ranger District, Idaho. To date, both still show 96 percent tree survival and additional growth, as compared to 30 percent survival of nonprotected trees. In addition, 200 acres (81 ha) contract-planted in 1979 also remain protected from depredation. However, associated costs are three times higher than contract control by baiting (Birch 1982, personal communication). Although expensive, this procedure should be considered when there are environmental hazards associated with baiting or where a long-term commitment to rebaiting cannot be assured (Barnes and Anderson 1982, personal communication). Problems associated with this method, other than cost, may include: breakage; compression of the tubing by extreme cold, snow, and frost heaving; and deformity of terminal buds and roots protruding through mesh openings (Anthony and others 1978:DC).

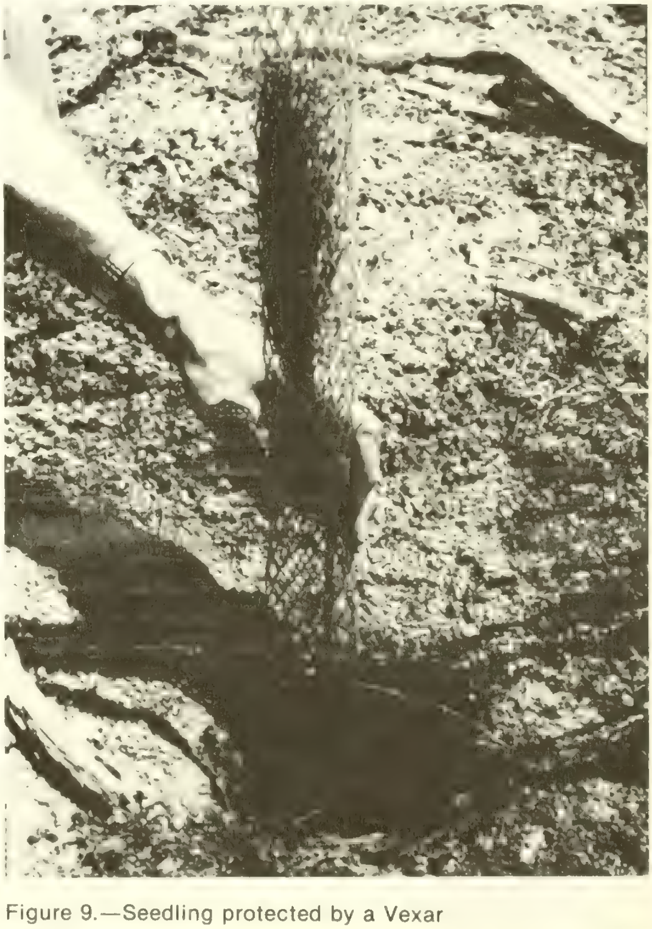

Figure 9.—Seedling protected by a Vexar tube.

7. Exclosures.—Exclosures protected study plots from invading gophers with variable success (Horn and Fitch 1942:HRR; Ellison and Aldous 1952:HRR). Workers, however, place little value on exclosures for real operational control. Small-mesh wire, sheet metal, or concrete fencing may be effective in local situations. For best protection from overland and subterranean invasion, fencing should extend 2 ft (0.6 m) below ground surface and 1 ft (0.3 m) above ground depending on expected snow depth (Cummings 1962:DC). Cummings reported that fencing with wire mesh or concrete deterred burrowing in canals or ditches, although fencing involved high costs.

8. Gas cartridges.—The placement of gas cartridges in pocket gopher burrow systems provides one alternative to baiting. But the technique is costly and relatively ineffective because gophers have such long burrow systems (Rost 1978:DC). Methods previously discussed show greater promise for future use, although this method of control could be applied in campgrounds or situations where other toxicants or trapping techniques are undesirable (Borrecco 1982, personal communication).

Timing of Treatment

Successful damage control requires organizational commitment, persistence, and the timely coordination of all regeneration practices. On forest plantations, time-of-treatment decisions must take into account density, size, and distribution of existing tree stock, as well as pocket gopher abundance. The entire area occupied by gophers must receive treatment and, if necessary, periodic retreatment (Moore and Reid 1951:HRR; Richens 1965:DC; Allen and others 1978:DC). The administration of control treatments must occur at appropriate times to achieve maximum population reductions. Managers should concentrate efforts on achieving lowest gopher densities during the seasons of highest probable depredation. Allen and others (1978:DC) thought treatment should take place before the young dispersed or during the winter season. Buchner and Rorabaugh (1979:DTF) stated that for maximum success, toxic baits should be applied when animals are most active and preferably before parturition. Barnes (1974:HRF), however, recommended fall treatments because earlier treatments did not adequately protect areas from rapid reinvasion. Gophers exhibit strong tendencies to reinvade areas newly vacated after control (Barnes 1974:HRF). Spring baitings or less frequent applications may suffice on sites with low reinvasion potential or supporting low gopher populations (Barnes and others 1970:DC). Treatment extending 60 ft (18 m) into a plantation perimeter could minimize reinvasion after poisoning (Allen and others 1978:DC).

In areas of heavy infestation, Birch (1978:DC) recommended fall baiting with a mechanical burrow builder before planting, followed by hand baiting for two subsequent summers to allow adequate establishment of young plantations. However, managers must monitor sites annually thereafter and promptly re-treat sites showing reinvasion.

Miller (1948:B) found control on agricultural lands best after the first heavy rains of autumn. Lower vegetation exists, gophers accept baits more readily, and workers locate runways and mounds more easily during this time. Control effectiveness increases in the fall because it precedes the winter and spring breeding seasons. Summer and fall usually are poor times for control on nonirrigated lands because gophers become less active and vegetation may obscure mounds, making probing difficult.

Gopher population size dictates the number and kind of treatments necessary (Barnes 1974:HRF). Any technique depends on variables that may include: the physical restraints of the environment, especially soil and topography; lack of quality conifer seed; budget restraints; insufficient personnel to administer programs; equipment; and ecological or political consideration (Tietjen 1973:DC; Barnes 1974:HRF; U.S. Department of Agriculture 1979:DTF).

RESEARCH NEEDS

A strong need exists to develop new methods and refine existing techniques for management of pocket gophers. Recently in the Western United States, the Pocket Gopher-Reforestation Activity Review Team (U.S. Department of Agriculture 1979:DC) created procedures for assessing gopher damage, identifying related problems and issues, evaluating control efforts, and making recommendations to guide future research and control. To date, the team has reviewed management and reforestation activities in USDA Forest Service Regions 4 and 6 only, but considers the findings representative of all Western States. The group identified a number of areas and issues in need of attention. Many of these are included in this section.

Improved solutions to gopher damage prevention and control require more information than is presently available. In many areas, problems are evident, but detailed surveys documenting damage are lacking. Budget limitations make it necessary to prioritize research needs and to determine areas where control is most important. Relationships between gopher depredation and economic loss must be evaluated on different areas to analyze the long-term costs and benefits of control and to choose techniques most warranted.

Control Methodology

1. Response to habitat manipulation.—Indirect control via habitat manipulation has potential use, but further information is necessary to evaluate how gopher populations will respond to habitat changes resulting from herbicides, various silvicultural systems, and various site preparation techniques. On most areas, there is a shortage of information identifying the forest communities and situations where preventive management could be most effective (Barnes 1982, personal communication). Development of general criteria to foretell problem areas might be valuable for land managers who are faced with difficult decisions in land-use or harvest-planning stages. Clearly defined relationships between gopher densities and specific habitat characteristics do not always exist (Volland 1973:HRF; Anderson 1976:HRF; Youmans 1979:HRF; Buchner and Rorabaugh 1979:DTF), but certain habitats can generally be correlated to high and low gopher populations. However, it is still necessary to evaluate each situation individually and maintain past and future studies for use as guides.

2. **Plastic seedling protectors.**—Further evaluation is needed on protective tubing such as Vexar. Although this method is promising, further improvements in preparation, transportation, and planting of enclosed seedlings are necessary to make the procedure more economically efficient (Anthony and others 1978:DC). Additional studies might determine whether this type of protective tube adversely affects seedling root development and tree growth.

3. **Poison baits.**—The development of new toxicants that might prove more effective, specific, or safer to people and nontarget wildlife is considered important. The best time for baiting treatments in different areas is still uncertain. The possibility of winter control and bait acceptance needs further study. Continued studies are needed of factors related to baiting mortality, including bait attractiveness, toxicity of poison, causes of varying rodent susceptibility, and bait duration. In 1978, Weyerhaeuser researchers looked at the possibility of enclosing baits in polyethylene bags (bagged bait) to extend duration, reduce baiting costs, and further combat reinvasion of existing burrow systems by dispersing gophers. At that time, results of their study seemed promising (Ray 1978, personal communication). Another suggestion involves further development of longer lasting toxic foam or grease for placement in artificial burrows. However, Marsh (1982, personal communication) indicated that past control efforts with existing toxic foams proved relatively ineffective on *T. bottae*. In the future, long-lived baits might meet with opposition from the Environmental Protection Agency.

4. **Hazards to nontarget species.**—Most studies do not indicate significant control-related hazards to nontarget species, but potential primary and secondary dangers of direct or indirect control practices are a major public concern. This is particularly true when treated areas occur in or near habitats of threatened or endangered species. Federal registration requirements for existing poisons and new toxicants are becoming increasingly restrictive. These same concerns are developing over herbicide use. Such uncertainties may limit future use of the baiting programs managers most commonly rely upon today. For this reason, further evaluation of control agents is necessary, and development of poison-free control measures is emphasized. In addition, opportunities to educate the public on these issues should not be overlooked.

5. **Feeding habits.**—Quantitative data on gopher feeding habits as they relate to reforestation will help predict problems and develop more effective control methods. Gopher population levels tolerable in conifer plantations should be assessed. Tree stocking levels able to withstand low to moderate gopher depredation need to determined. Radwin and others (1982:FF) compared essential oil content in ponderosa pine seedlings from nine different regions. Gophers exposed to seedlings showed different degrees of feeding preference. Further study may lead to the discovery or development of naturally gopher-resistant plant species and less vulnerable seedling stock. Such findings might also lead to development of some other gopher repellent or deterrent. However, the adaptable feeding preferences of gophers may limit the potential of this approach.

6. **Repellents.**—Potential for further development of repellents on forest lands exists. Information detailing subsequent effects to both the gophers and the trees themselves will be needed. In the past, repellents have provided protection for buried cables (Tigner and Landstrom 1968:DC), and Barnes (1973:DTF) cites a report of similar success with fruit trees.

7. **Grooming inhibitors.**—The use of special tacky substances or wetting agents placed in burrow systems or in the soil might inhibit animal grooming and condition gophers to avoid certain areas, abandon burrows, or become less able to survive. Such sticky substances are yet to be lab-tested, and adequate evaluation for control would require further behavioral research, including studies on food-handling and grooming behavior and the animal's response to these substances. Successful operational control is deemed unlikely.

8. **Reproductive inhibitors.**—The use of reproductive inhibitors has been considered, but the probability of success is judged low (U.S. Department of Agriculture 1979:DC). Some believe fossorial rodents communicate territoriality and reproductive status via specific chemical signals (pheromones) (Brown 1971:RGA). Employing these as repellents or to inhibit reproduction may be possible, but unlikely.

Integrated Management

The means to effective and efficient control most likely lies in a holistic approach. This entails integrating dynamics of gopher population structure and growth, economic analysis, land management options, and an understanding of forest ecology into an ecosystem-oriented analysis of the problems. On forest sites with serious gopher problems, successful regeneration often depends on the land manager's ability to integrate two or more control methods. In the future, emphasis on various control combinations and prevention of population buildups will increase. Managers should continue to familiarize themselves with pocket gopher problems and the ways to best use existing control techniques.

LITERATURE REVIEW

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B	Behavior	40
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General References (GR)

Adams, A. W. Wildlife surveys and investigations. Bismark, ND: North Dakota State Game and Fish Department; 1965. 17 p.

Allen, J. A. Notes on the mammals of Iowa. Boston Society of Natural History, Proceedings 13: 178-194; 1869.

Allen, J. A. Notes on the mammals of portions of Kansas, Colorado, Wyoming and Utah. Part I: On the mammals of middle and western Kansas. Essex Inst. Bull. 6(2): 43-52; 1874.

Allen, J. A. Notes on the mammals of portions of Kansas, Colorado, Wyoming, and Utah. Part IV: On the mammals of the Great Salt Lake Valley, Utah. Essex Inst. Bull. 6: 61-66; 1874.

Allen, J. A. List of mammals collected by Mr. Charles P. Rowley in the San Juan region of Colorado, New Mexico, and Utah, with descriptions of new species. Am. Mus. Nat. Hist. Bull. 5: 69-84; 1893.

Allen, J. A. On the mammals of Aransas County, Texas, with descriptions of new forms of *Lepus* and *Oryzomys*. Am. Mus. Nat. Hist. Bull. 6(6): 165-198; 1894.

Allen, J. A. List of mammals collected in the Black Hills region of South Dakota and in western Kansas by Mr. Walter W. Granger with field notes by the collector. Am. Mus. Nat. Hist. Bull. 7: 259-274; 1895.

Allen, J. A. List of mammals collected by Mr. Walter W. Granger in New Mexico, Utah, Wyoming and Nebraska, 1895-1896, with field notes by the collector. Am. Mus. Nat. Hist. Bull. 8: 241-258; 1896.

Allen, J. A. On mammals collected in Bexar County and vicinity, Texas, by Mr. H. P. Attwater, with field notes by the collector. Am. Mus. Nat. Hist. Bull. 8(5): 47-80; 1896.

Allen, J. A. Mammals from Beaver County, Utah, collected by the Museum expedition of 1904. Brooklyn Inst. Mus. Sci. Bull. 1: 117-122; 1905.

Allen, P. Kansas mammals. Kansas State Teachers College, Emporia, Inf. Stud. in Educ. Bull. 20(5): 1-62; 1940.

Ames, A. E. Mammalia of Minnesota. Minn. Acad. Sci. Bull. 1: 68-71; 1874.

Anderson, R. J.; Barnes, V. G.; Bruce, A. M. A bibliography of pocket gophers: Family Geomyidae. Weyerhaeuser For. Pap. No. 16. Centralia, WA: Weyerhaeuser Company, Forestry Research Center; 1976. 50 p.

Anthony, H. E. Field book of North American mammals. New York: G. P. Putnam and Sons; 1928. 674 p.

Bailey, B. Mammals of Sherburne County, Minnesota. J. Mammal. 10(2): 153-164; 1929.

Bailey, V. A biological survey of Texas. North American Fauna 25. Washington, DC: U.S. Department of Agriculture, Bureau of Biological Survey; 1905. 222 p.

Bailey, V. A biological survey of North Dakota. North American Fauna 49. Washington, DC: U.S. Department of Agriculture, Bureau of Biological Survey; 1927. 226 p.

Bailey, V. Mammals of New Mexico. North American Fauna 53. Washington, DC: U.S. Department of Agriculture, Bureau of Biological Survey; 1931. 412 p.

Bailey, V. The mammals and life zones of Oregon. North American Fauna 55. Washington, DC: U.S. Department of Agriculture, Bureau of Biological Survey; 1936. 416 p.

Baird, S. F. Characteristics of some new species of mammalia collected by the U.S. and Mexican Boundary Survey. Philadelphia Academy of Science, Proceedings 7: 331-333; 1855.

Baird, S. F. Mammals of North America. Pacific Railroad Survey, vol. 8, part I. Washington, DC: War Department; 1857. 757 p.

Baird, S. F. Report of exploration and surveys from the Mississippi River to the Pacific Ocean. Pacific Railroad Survey, vol. 8. Washington, DC: War Department; 1857. 394 p.

Baird, S. F. Report of mammals collected by the survey. Pacific Railroad Survey, Zoology Report, vol. 10, part I. Washington, DC: War Department; 1857: 6-9.

Baird, S. F. Mammals of the boundary. U.S. and Mexican Boundary Survey, Part II, Zoology. Washington, DC: U.S. Department of the Interior; 1859. 62 p.

Baird, S. F. Report on Gunnison and Beckwith's route. Pacific Railroad Survey, vol. 20, part 4, No. 1. Washington, DC: War Department; 1859. 8 p.

Baker, A. B. Mammals of western Kansas. In: Transactions, 1887 Kansas Academy of Science: 20th Annual Meeting; 1887 October 26-28; Topeka, KS. Topeka, KS: Kansas Academy of Science; 1889: 56-58.

Baker, R. H. Notes on mammals of Galveston and Mustang Islands. Texas. J. Mammal. 19(4): 505; 1938.

Bangs, O. The land mammals of peninsular Florida and coast region of Georgia. Boston Society of Natural History, Proceedings 28(7): 157-235; 1898.

Barnes, C. T. Mammals of Utah. University of Utah Bull. 12(15): 1-176; 1922.

Barnes, C. T. Utah mammals. University of Utah Bull. 17(12): 1-183; 1927.

Beed, W. E. A preliminary study of the animal ecology of the Niobra Game Reserve. Lincoln, NB: University of Nebraska Conservation Department; 1936 October. 33 p. Unnumbered bulletin.

Benson, S. B. A biological reconnaissance of Navajo Mountain, Utah. Univ. Calif. Publ. Zool. 40(14): 439-456; 1935.

Black, J. D. Mammals of northwestern Arkansas. J. Mammal. 17(1): 29-35; 1936.

Blair, W. F. Faunal relationships and geographic distribution of mammals in Oklahoma. Am. Midl. Nat. 22(1): 85-133; 1939.

Blair, W. F. A contribution to the ecology and faunal relationships of the mammals of the Davis Mountain Region, southwestern Texas. Misc. Publ. 46. Ann Arbor, MI: University of Michigan, Museum of Zoology; 1940. 39 p.

Borell, A. E.; Bryandt, M. D. Mammals of the Big Bend area of Texas. Univ. Calif. Publ. Zool. 48(1): 1-62; 1942.

Brandt, J. F. Beitrage zur nahern Kenntniss der Saugethiere Russlands. Ser 6 and 7. St. Petersburg, Russia: Mem. Acad. Imp. Sci.; 1855. 365 p.

Brants, A. Het geslacht der Muizen doo Linnaeus Opgesteld, volgens de tegenswoordige Toestand der Wetenscap in Familien, geslachten en Soorten Verdeeld door A. Brants. Berlyn: Academische Boekdrukkery; 1827. 190 p.

Brinnell, J. The biota of the San Bernardino Mountains: the mammals. Univ. Calif. Publ. Zool. 5(1): 134-160; 1908.

Brinnell, J. Native California rodents in relation to water supply. J. Mammal. 14: 293-298; 1933.

Brinnell, J. Review of the recent mammal fauna of California. Univ. Calif. Publ. Zool. 40(2): 71-234; 1933.

Brinnell, J.; Linsdale, J. M. Vertebrate animals of Points Lobos Reserve, 1934-1935. Publ. No. 481. Washington, DC: Carnegie Institute; 1936: 142-143.

Brinnell, J.; Storer, T. I. Animal life in the Yosemite. Berkeley: University of California Press; 1924. 752 p.

Brinnell, J.; Swarth, H. S. An account of the birds and mammals of the San Jacinto area of southern California, with remarks upon the behavior of geographical races of the margins of their habitat. Univ. Calif. Publ. Zool. 10: 197-417; 1913.

Durrant, S. D. Mammals of Utah. Univ. Kans., Mus. Nat. Hist., Publ. 6: 1-549; 1952.

Elliot, D. G. Synopsis of the mammals of North America and adjacent seas. Zool. Ser., Vol. 2. Chicago, IL: Field Columbian Museum; 1901. 471 p.

Elliot, D. G. A check list of the mammals of the North American continent, the West Indies and the neighboring seas. Zool. Ser., Vol. 6, Publ. 105. Chicago, IL: Field Columbian Museum; 1905. 761 p.

Elliot, D. G. A catalogue of the collection of the mammals in the Field Columbian Museum. Zool. Ser., Vol. 8, Publ. 115. Chicago, IL: Field Columbian Museum; 1907. 694 p.

Evermann, B. W.; Butler, A. W. Preliminary list of Indiana mammals. In: Proceedings, 1893 Indiana Academy of Science; 1893 December 27-28; Indianapolis, IN. Brookville, IN: Indiana Academy of Science; 1894: 124-139.

Fischer, J. B. Synopsis mammalium. Stuttgardia: Sumptibus J. G. Cottae; 1829. 752 p.

Giebel, C. G. A. Odontographie. Leipzig: A. Abel; 1885. 129 p.

Giebel, C. G. A. Beitratrage zum Osteologie den Nagethiere. Berlin: G. Bosselmann; 1857. 72 p.

Giebel, C. G. A. Die Saugethiere in Zoologischer, Anatomischer and Palaeontologischer Beziehung. Leipzig: A. Abel; 1859. 1108 p.

Gill, T. N. Arrangement of the families of mammals with analytical tables. Smithsonian Miscellaneous Collection, Publ. 230. Washington, DC: Smithsonian Institution; 1872; 11: 1-98.

Glass, B. P. Report on the mammals of the Black Mesa region, Oklahoma. In: Proceedings, 1949 Oklahoma Academy of Science: 38th Annual Meeting; 1949 December 2-3; Enid, OK. Norman, OK: Oklahoma Academy of Science; 1951; 30: 26-30.

Godman, J. D. American natural history: Part I-Mastology. Philadelphia: H. C. Carey and J. Lea; 1826-1829. Vol. 3.

Goldman, E. A. New mammals from Arizona, New Mexico and Colorado. Wash. Acad. Sci. J. 23(10): 463-473; 1933.

Goldman, E. A. Three new rodents from southern Utah. Biological Society of Washington, Proceedings 55: 75-78; 1942.

Hall, E. R. Critical comments on mammals from Utah, with descriptions of new forms from Utah, Nevada and Washington. Univ. Calif. Publ. Zool. 37(1): 11-13; 1931.

Hall, E. R. Mammals of Nevada. Berkeley: University of California Press; 1946. 710 p.

Hall, E. R. Handbook of mammals of Kansas. Misc. Publ. No. 7. Lawrence, KS: University of Kansas, Museum of Natural History; 1955. 303 p.

Hall, E. R.; Davis, W. B. Notes on Arizona rodents. Biological Society of Washington, Proceedings 47: 51-56; 1934.

Hall, E. R.; Kelson, K. R. The mammals of North America. New York: Ronald Press; 1959. Vol. 2.

Hall, E. R. The mammals of North America. 2d ed. New York: John Wiley & Sons; 1981. Vol. 2.

Harlan, R. Fauna Americana. Philadelphia: Finley; 1825. 318 p.

Harper, F. Mammal notes from Randolf County, Georgia. J. Mammal. 10(1): 84-85; 1929.

Hayward, C. L. A bibliography of Utah mammalogy; including references to names and type localities applied to Utah mammals. In: Proceedings, 1936 Utah Academy of Science, Arts, and Letters: 29th Annual Meeting; 1936 May 22-23; Salt Lake City, UT. Provo, UT: Utah Academy of Science, Arts, and Letters; 1936: 121-146.

Hayward, C. L. A bibliography of Utah mammalogy, including references to names and type localities. Great Basin Nat. 2(4): 125-136; 1941.

Hayward, C. L. Alpine biotic communities of the Uinta Mountains. Utah. Ecol. Monogr. 22(2): 93-120; 1952.

Henshaw, H. W.; Birdseye, C. The mammals of Bitterroot Valley, Montana, in relation to spotted fever. Circ. No. 82. Washington, DC: U.S. Department of Agriculture, Bureau of Biological Survey; 1911. 24 p.

Hibbard, C. W. A checklist of Kansas mammals. Kansas Academy of Science, Transactions 47(1): 61-88; 1944.

Hoffmeister, D. F. Observations on mammals in southeastern Arizona. Misc. Publ. No. 129. Chicago, IL: Chicago Academy of Science and Natural History; 1954. 1 p.

Howell, A. H. Notes on mammals of the middle Mississippi Valley, with description of a new woodrat. Biological Society of Washington, Proceedings 23: 23-33; 1910.

Ingles, L. G. Mammals of California. Stanford, CA: Stanford University Press; 1947. 258 p.

Jackson, H. H. T. A preliminary list of Wisconsin mammals. Wisc. Nat. Hist. Soc. Bull. 6(1-2): 1-33; 1908.

Jackson, H. H. T.; Warfel, H. E. Mammals of the regions adjacent to the salt plains in Oklahoma. Univ. Okla. Biol. Sur. Publ. 5(4): 65-72; 1933.

Johnson, C. E. Recollections of the mammals of northwestern Minnesota. J. Mammal. 11(4): 435-452; 1930.

Kennerly, C. B. R. Report upon the mammals of the route. Pacific Railroad Survey, 10 parts. Washington, DC: War Department; 1859; 6(2): 18.

Kennicott, R. The quadrupeds of Illinois, injurious and beneficial to the farmer. Agric. Rep. for 1857. Washington, DC: U.S. Patent Office; 1858: 52-110.

Knox, M. V. B. Kansas mammalia. In: Transactions, 1875 Kansas Academy of Science: 8th Annual Meeting; 1875 October 12-13; Topeka, KS. Lawrence, KS: Kansas Academy of Science; 1906: 19-22.

Kuhl, H. Beitrage zur Zoologie und vergleichenden Anatomie. Frankfurt-am-Main: Herman; 1820. 464 p.

Lantz, D. E. A list of Kansas mammals. In: Transactions, 1903 Kansas Academy of Science: 36th Annual Meeting; 1903 November 26-28; Manhattan, KS. Topeka, KS: Kansas Academy of Science; 1905: 171-178.

Lantz, D. E. Kansas mammals in their relation to agriculture. Bull 129. Manhattan, KS: Kansas Agricultural Experiment Station; 1905: 331-404.

Lantz, D. E. Additions and corrections to the list of Kansas mammals. In: Transactions, 1906 Kansas Academy of Science: 39th Annual Meeting; Topeka, KS. Topeka, KS: Kansas Academy of Science; 1907: 214-217.

Leraas, H. J. Notes on mammals from west-central Minnesota. J. Mammal. 23(3): 343-345; 1942.

Lesson, R. P. Manuel de mammalogie, ou histoire naturelle des mammiferes. Paris: Roret; 1827. 441 p.

Lichtenstein, K. H. H. Ueber aussere Backentaschen an Nagethieren. Abhandlungen der Koniglichen Akademie der Wissenschaften zu Berlin; 1822: 13-20.

Linsdale, J. Mammals of a small area along the Missouri River. J. Mammal. 9(2): 140-146; 1928.

Marshall, W. H. A survey of the mammals of the islands in Great Salt Lake, Utah. J. Mammal. 21(2): 144-159; 1940.

Merriam, C. H. Descriptions of twenty-six new species of North American mammals. North American Fauna 4. Washington, DC: U.S. Department of Agriculture, Bureau of Biological Survey; 1890. 60 p.

Miller, G. S., Jr.; Kellogg, R. List of North American recent mammals. U.S. Natl. Mus. Bull. 205. Washington, DC: Smithsonian Institution; 1955.

Mitchill, S. L. Undescribed little quadruped of Georgia. New York Medical Repository 5: 89; 1802.

Nelson, E. W. Smaller mammals of North America. Natl. Geogr. 33(5): 371-493; 1918.

Poole, A. J.; Schantz, V. S. Catalog of the type specimens of mammals in the United States National Museum, including the biological surveys collection. U.S. Natl. Mus. Bull. 178. Washington, DC: Smithsonian Institution; 1942. 705 p.

Rafinesque, C. S. Description of seven new genera of North American quadrupeds in Museum of Natural Sciences. Am. Mo. Mag. 2(1): 44-45; 1817.

Richardson, J. Fauna Boreali-Americana or the zoology of the northern parts of British America. London: J. Murray; 1892. Vol. I.

Richardson, J. Report on North American zoology. Brit. Assoc. Adv. Sci., Annu. Rep. 1836, 5: 121-124; 1837.

Richardson, J. The zoology of Captain Beechey's voyage. London: H. G. Bohn; 1839. 180 p.

Sanderson, G. C. Small-mammal population of a prairie grove. J. Mammal. 31(1): 17-25; 1950.

Say, T. Account of expedition from Pittsburgh to Rocky Mountains, performed in 1819 and 1820, by order of J. C. Calhoun, Secretary of War, under command of Stephen H. Long, from notes of Major Long, T. Say, and other gentlemen of the exploring party, by Edin James. (Long's Expedition to the Rocky Mountains). Philadelphia: H. C. Carey and J. Lea; 1823. Vol. I.

Schendel, R. R. Mammals of Payne County, Oklahoma. In: Proceedings, 1941 Oklahoma Academy of Science: 30th Annual Meeting; 1941 December 4-5; Edmond, OK. Norman, OK: Oklahoma Academy of Science; 1942: 75-76.

Schinz, H. R. Systematisches Verzeichniss aller bis jetzt bekannten Saugethiere: oder Synopsis mammalium nach dem Cuvier'schen System. Solothurn: Jent and Gassmann; 1844-1845. Vol. I.

Schmidt, F. J. W. Mammals of western Clark County, Wisconsin. J. Mammal. 12(2): 99-117; 1931.

Shaw, G. General zoology, or systematic natural history. London: G. Kearsley; 1801. Vols. I and II.

Sherman, H. B. Notes on some Florida mammals. J. Mammal. 10(3): 258-259; 1929.

Simpson, G. G. The principles of classification and a classification of mammals. Am. Mus. Natl. Hist. Bull. 85. Washington, DC: Smithsonian Institution; 1945. 350 p.

Stoner, R. D. The rodents of Iowa. Iowa Geol. Surv. Bull. 5: 1-172; 1918.

Storer, T. I.; Evans, F. C.; Palmer, F. G. Some rodent populations in the Sierra Nevada of California. Ecol. Monogr. 14: 165-192; 1944.

Sturber, T. The mammals of Minnesota. St. Paul, MN: Minnesota Department of Conservation, Game and Fish; 1932. 84 p.

Swanson, G.; Sturber, T.; Roberts, T. S. The mammals of Minnesota. Tech. Bull. 2. St. Paul, MN: Minnesota Department of Conservation; 1945. 108 p.

Vaughan, T. A. Mammals of the San Gabriel Mountains of California. Univ. Kans., Mus. Nat. Hist., Publ. 7(9): 513-582; 1954.

Warren, E. R. The mammals of Colorado, their habits and distribution. Norman: University of Oklahoma Press; 1943. 330 p.

Waterhouse, G. R. A natural history of the Mammalia. Vol. II, Rodentia. London: H. Balliere; 1848.

Wied-Neuwied, M. von. Uber einige Nager mit ausseren Backentaschen aus dem westlichen Nord-America. Acta. Acad. Caes. Leop. Carol. 19: 20; 1839.

Geologic and Historic References (GH)

Brown, B. The Conard fissure, a Pleistocene bone-deposit in northern Arkansas, with descriptions of two genera and twenty new species of mammals. Mem. Am. Mus. Nat. Hist. 9: 157-208; 1908.

British Museum of Natural History, Department of Zoology. Catalogue of the bones of mammalia in the collection of the British Museum. London: British Museum of Natural History; 1862. 296 p.

Cahalane, V. H. Mammals of the Chiricahua mountains, Cochise Co., Arizona. J. Mammal. 20: 418-440; 1939.

Camp, C. L. (and others). Bibliography of fossil vertebrates, 1928-1933. Special Papers 27 and 42. New York, NY: Geological Society of America; 1940.

Camp, C. L. (and others). Bibliography of fossil vertebrates, 1939-1943. Memoir 37. New York, NY: Geological Society of America; 1949. 371 p.

Carey, M. A biological survey of Colorado. North American Fauna 33. Washington, DC: U.S. Department of Agriculture, Bureau of Biological Survey; 1911. 256 p.

Childs, H. E., Jr.; Howard, W. E. The vertebrate fauna of San Joaquin Experiment Range. Misc. Paper No. 19. Berkeley, CA: California Forest and Range Experiment Station; 1955. 20 p.

Cockrum, E. L. Mammals of Kansas. Univ. Kans., Mus. Nat. Hist., Publ. 7(1): 1-303; 1952.

Corey, C. B. Mammals of Illinois and Wisconsin. Publ. 153, Zool. Ser. 11. Chicago, IL: Field Museum of Natural History; 1912. 505 p.

Coues, E. A critical review of the North American Rodentia. Philadelphia Academy of Natural Science, Proceedings 27: 272-327; 1875.

Dalquest, W. W. Mammals of Washington, vol. 2. Lawrence, KS: University of Kansas Museum of Natural History; 1948. 44 p.

Davis, W. B. The recent mammals of Idaho. Caldwell, ID: Caxton Printers; 1939. 400 p.

Davis, W. B. Mammals of the Guadalupe Mountains of western Texas. Occ. Pap. 7. Baton Rouge, LA: Louisiana State University Museum of Zoology; 1940: 69-84.

Davis, W. B.; Robertson, J. L. The mammals of Culberson County, Texas. J. Mammal. 25(3): 254-273; 1944.

Dellinger, S. C.; Black, J. D. Notes on Arkansas mammals. J. Mammal. 21(2): 187-191; 1940.

Dice, L. R. Notes on some mammals of Riley County, Kansas. J. Mammal. 4(2): 107-112; 1923.

Duck, L. G.; Fletcher, J. B. A survey of the game and furbearing animals of Oklahoma. P. R. Ser. 2. Oklahoma City, OK: Oklahoma State Game and Fish Commission; 1945. 144 p.

Duck, L. G.; Frye, J. C.; Leonard, A. B. Reconnaissance of Pleistocene deposits in north central Kansas. State Geol. Sur. Kans. Bull. 52(1): 1-28; 1944.

Duck, L. G.; Wilson, J. A. A new rodent from subsurface stratum in Bee County, Texas. J. Paleo. 24(5): 621-623; 1950.

Franzen, D. S. The pocket gopher, *Geomys quinni* (McGraw) in the Rexford fauna, Blancan age, of southwestern Kansas. Kansas Academy of Science, Transactions 50(1): 55-59; 1947.

Frey, R. W.; Voorhies, M. R.; Howard, J. D. Estuaries of the Georgia Coast USA sedimentology and biology. Part 8: Fossil and recent skeletal remains in Georgia estuaries. Senckenbergiana Marit. 7: 257-295; 1975.

Gawne, C. E. Rodents from the Zia sand Miocene of New Mexico USA. Am. Museum Novitates 2586. New York: American Museum of Natural History; 1975. 25 p.

Gazin, C. L. The late Cenozoic vertebrate faunas from the San Pedro Valley, Arizona. U.S. National Museum, Proceedings 92(3155): 475-518; 1942.

Gidley, J. W. Preliminary report of fossil vertebrates of the San Pedro Valley, Arizona and descriptions of new species of Rodentia and Lagomorpha. Prof. Pap. 131-E. Washington, DC: U.S. Department of the Interior, U.S. Geological Survey; 1922: 119-128.

Gidley, J. W.; Gazin, C. L. New mammalia in the Pleistocene fauna from Cumberland Cave. J. Mammal. 14(4): 343-357; 1933.

Gillette, D. D. Late quaternary mammals from the St. Marks River, Wakulla County, Florida USA. Fla. Sci. 39(2): 120-122; 1976.

Guilday, J. E. Saber-toothed cat *Smilodon floridanus* and associated fauna from a Tennessee USA cave, the 1st American Bank site. J. Tenn. Acad. Sci. 52(3): 84-94; 1977.

Hay, O. P. The Pleistocene of North America and its vertebrated animals from the states east of the Mississippi River and from the Canadian provinces east of longitude 95. Publ. 322. Washington, DC: Carnegie Institute of Washington; 1923. 499 p.

Hay, O. P. The Pleistocene of the middle region of North America and its vertebrated animals. Publ. 322A. Washington, DC: Carnegie Institute of Washington; 1924. 385 p.

Hay, O. P. The pleistocene of the western region of North America and its vertebrated animals. Publ. 322B. Washington, DC: Carnegie Institute of Washington; 1927. 346 p.

Hay, O. P. Second bibliography and catalogue of the fossil vertebrata of North America. Publ. 390. Washington, DC: Carnegie Institute of Washington; 1929. 1990 p.

Hibbard, C. W. An upper Pliocene fauna from Meade County, Kansas. In: Transactions, 1937 Kansas Academy of Science: 69th Annual Meeting; 1937 April 1-3; Manhattan, KS. Topeka, KS: Kansas Academy of Science; 1938: 239-265.

Hibbard, C. W. Notes on some vertebrates from the Pleistocene of Kansas. In: Transactions, 1937 Kansas Academy of Science: 69th Annual Meeting; 1937 April 1-3; Manhattan, KS. Topeka, KS: Kansas Academy of Science; 1937: 233-237.

Hibbard, C. W. The Borchers fauna, a new Pleistocene interglacial fauna from Meade County, Kansas. State Geol. Surv. Kans. Bull. 38(7): 197-220; 1941.

Hibbard, C. W. Mammals of the Rexroad fauna from the upper Pliocene of southwestern Kansas. In: Transactions, 1941 Kansas Academy of Science: 73rd Annual Meeting; 1941 April 3-5; Manhattan, KS. Lawrence, KS: Kansas Academy of Science; 1941: 265-313.

Hibbard, C. W. Palaeoecology and correlation of the Rexroad fauna from the upper Pliocene of southwestern Kansas, as indicated by the mammals. Univ. Kans. Sci. Bull. 1(6): 79-104; 1941.

Hibbard, C. W. Pleistocene vertebrate paleontology in North America. Geol. Soc. Am. Bull. 60: 1417-1428; 1949.

Hibbard, C. W.; Zakrzewski, R. J.; Eshelman, R. E.; Edmund, G.; Griggs, C. D.; Griggs, C. Mammals from the Kanopolis local fauna Pleistocene yarmouth of Ellsworth County, Kansas, USA. Contributions of the Museum of Paleontology, University of Michigan. 25(2): 11-43; 1978.

Howell, A. B. Surface wanderings of fossorial mammals. J. Mammal. 3: 19-22; 1922.

Korth, W. W. Geomyoid rodents from the Valentine formation of Knox County, Nebraska USA. Andrew Carnegie Mus. Nat. Hist. Bull. 48(16): 287-310; 1979.

Lawrence, B. Bones from the Governador area. Columbia Stud. Archeol. and Ethnol. 2(1): 73-78; 1944.

Li, C. K. A probable geomyid rodent from middle Miocene on Linchu Shatung, China. Vertebr. Palasiat. 12(1): 43-53; 1974.

Lindsay, E. H.; Van Devender, T. R. The California, USA, Wash, vertebrate fauna late Cenozoic of the San Pedro Valley, Arizona, USA. J. Ariz. Acad. Sci. 8: Supplement; 1973. 46 p.

Martin, L. D.; Bennett, D. K. The burrows of the Miocene beaver palaeocastor western Nebraska, USA. Palaeogeogr., Palaeoclimatol., Palaeoecol. 22(3): 173-194; 1977.

Matthew, W. D. The evolution of the mammals in the Eocene. Zoological Society of London, Proceedings; 1927: 947-985.

McGrew, P. O. An early Pleistocene (Clancan) fauna from Nebraska. Field Mus. Nat. Hist. Geol. Ser. 9(2): 31-66; 1944.

McNab, B. K. The metabolism of fossorial rodents: a study of convergence. Ecology. 47(5): 712-733; 1966.

Merriam, J. C. Tertiary mammal beds of Virgin Valley and Thousand Creek in northwestern Nevada: Part II, vertebrate faunas. Univ. Calif. Geol. Dep. Bull. 6(11): 199-304; 1911.

Merriam, J. C.; Sinclair, W. J. Tertiary faunas of the John Day region. Univ. Calif. Geol. Dep. Bull. 5(11): 171-205; 1907.

Munthe, J. *Gregorymys larsoni* new species Rodentia: Geomyidae from the Miocene of Colorado USA. Paleo Bios. 26. Berkeley, CA: University of California, Museum of Paleontology; 1977: 1-2.

Opdyke, N. D.; Lindsay, E. H.; Johnson, N. M.; Downs, T. The paleo magnetism and magnetic polarity stratigraphy of the mammal bearing section of Anza Borrego State Park, California. Quat. Res. 7(3): 316-329; 1977.

Parmalee, P. W.; Munson, P. J.; Guilday, J. E. The Pleistocene mammalian fauna of Harrodsburg crevice, Monroe County, Indiana, USA. Natl. Speleol. Soc. Bull. 40(2): 64-73; 1978.

Rensberger, J. M. Function in the cheek tooth evolution of some hyposodont geomyid rodents. J. Paleontol. 49(1): 10-22; 1975.

Rinker, G. C. *Cratogeomys castanops* from a recent terrace in southwestern Kansas. J. Mammal. 22(1): 88; 1941.

Romer, A. S. Vertebrate paleontology. 2nd ed. Chicago: University of Chicago Press; 1945. 687 p.

Scott, W. B. *Protoptychus hatcheri*, a new rodent from the Uinta Eocene. Philadelphia Academy of Natural Science, Proceedings 47: 269-286; 1895.

Simpson, G. G. Pleistocene mammals from a cave in Citrus County, Florida. Am. Mus. Novitates 328. New York: American Museum of Natural History; 1928. 16 p.

Stevens, M. S. Further study of the castolon local fauna arikareean early Miocene, Big Bend National Park, Texas, USA. Pearch-Sellards Series, Texas Memorial Museum, No. 28. Beaumont, TX: Lamar University; 1977. 69 p.

Stewart, J. D. Mammals of the trapshoot local fauna, late Pleistocene, of Rooks County, Kansas USA. In: Proceedings 1978 Nebraska Academy of Science and Affiliated Societies; 1978 April 14-15; Lincoln, NB. Lincoln, NB: Nebraska Academy of Science and Affiliated Societies; 1978: 45-46.

Storer, J. E. Mammals of the Hand Hills formation, southern Alberta, Canada. In: Churcher, C. S., ed. Essays on palaeontology in honor of Lorbshano Russel. Misc. Publ. Toronto, ON: Royal Ontario Museum of Life Science; 1976: 186-209. ISBN 0-88854-157-0.

Voorhies, M. R. A new genus and species of fossil kangaroo rat and its burrow. J. Mammal. 56: 160-176; 1975.

Waters, J. H. Second find of *Thomomys talpoides* from late Pleistocene in Kansas. J. Mammal. 37(4): 540-542; 1956.

Webb, S. D. A history of savanna vertebrates in the new world, Part I: North America. In: Johnston, R. F. C.; Frank, P. W.; Michener, C. D., eds. Annual review of ecology and systematics, vol. 8. Palo Alto, CA: Annual Reviews, Inc.; 1977: 355-380. ISBN 0-8243-1408-5.

White, J. A.; Downs, T. A new *Geomys* from the Vallecito Creek Pleistocene of California. Los Angeles County Mus. Contrib. Sci. 42: 1-34, 1961.

Wilson, R. W. A rodent fauna from later Cenozoic beds of southwestern Idaho. Publ. 440. Washington, DC: Carnegie Institute of Washington; 1933: 117-135.

Wilson, R. W. The Pleistocene mammalian fauna from the Carpinteria asphalt. Publ. 440. Washington, DC: Carnegie Institute of Washington; 1933: 59-76.

Wilson, R. W. A Pliocene rodent fauna from Smith's Valley, Nevada. Publ. 473. Washington, DC: Carnegie Institute of Washington; 1936: 15-24.

Wilson, R. W. Pliocene rodents of western North America. Publ. 487. Washington, DC: Carnegie Institute of Washington; 1937: 21-73.

Wood, A. E. Evolution and relationships of the Heteromyid rodents with new forms from the Tertiary of western North America. Carnegie Mus. Annu. 24: 73-262; 1935.

Wood, A. E. Geomyid rodents from the middle tertiary. Am. Mus. Novitates. No. 866. New York: American Museum of Natural History; 1936. 31 p.

Zittel, K. A. von. Textbook of palaeontology. Vol. 3: Mammalia. London: MacMillan; 1925. 316 p.

Distribution and Taxonomy (DT)

Allen, J. A. Descriptions of four new species of *Thomomys* with remarks on other species of the genus. Am. Mus. Natur. Hist. Bull. 5: 47-68; 1893.

Allred, D. M. Small mammals of the National Reactor Testing Station, Idaho, USA. Great Basin Nat. 33(4): 246-250; 1973.

Alston, E. R. On the classification of the order Glires. Zoological Society of London, Proceedings; 1876: 61-98.

Anderson, S. Taxonomy of gophers, especially *Thomomys* in Chihuahua, Mexico. Systematic Zool. 15(3): 189-198; 1966.

Bailey, V. The pocket gophers of the United States. Bull. No. 5. Washington, DC: U.S. Department of Agriculture, Division of Ornithology and Mammalogy; 1895. 47 p.

Bailey, V. Revision of the pocket gophers of the genus *Thomomys*. North American Fauna 39. Washington, DC: U.S. Department of Agriculture, Bureau of Biological Survey; 1915. 136 p.

Baker, R. H. The taxonomic status of *Geomys breviceps texensis* Merriam and *Geomys bursarius illanensis* Bailey. J. Mammal. 31(3): 348-349; 1950.

Baker, R. H. The pocket gophers (Genus *Thomomys*) of Coahuila, Mexico. Univ. Kans., Mus. Nat. Hist., Publ. 5(28): 499-514; 1953.

Baker, R. H.; Glass, B. P. The taxonomic status of the pocket gophers, *Geomys bursarius* and *Geomys breviceps*. Biological Society of Washington, Proceedings 64: 55-58; 1951.

Baker, R. H.; Williams, S. L. *Geomys tropicalis*. Mammal. Species 35: 1-4; 1974.

Beer, J. R. The pocket gopher in Minnesota. Minn. Sci. 23(4): 5; 1967.

Benson, S. B.; Tillotson, D. F. Descriptions of two species of pocket gopher (*Thomomys bottae*) from Sonora. Biological Society of Washington, Proceedings 52: 151-153; 1939.

Best, T. L. Ecological separation of three genera of pocket gophers (Geomyidae). Ecology. 54(6): 1311-1319; 1973.

Blossom, P. M. Description of a new race of pocket gopher (*Geomys lutescens hylacus*) from northwestern Nebraska. Occ. Pap. No. 368. Ann Arbor, MI: University of Michigan, Museum of Zoology; 1938. 1 p.

Boeer, W. J.; Schmidly, D. J. Terrestrial mammals of the riparian corridor in Big Bend National Park. In: Johnson, R. Roy; Jones, Dale A., tech. coords. Importance, preservation and management of riparian habitat: a symposium; 1977 July 9; Tucson, AZ. Gen. Tech. Rep. RM-43. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station; 1977: 212-217.

Bond, S. I. An annotated list of the mammals of San Diego County, California USA. San Diego Society of Natural History, Transactions 18(4): 229-247; 1977.

Burt, W. H. A new pocket gopher of the genus *Thomomys* from Utah. Biological Society of Washington, Proceedings 44: 37-40; 1931.

Chamberlain, N. V. *Thomomys bottae aureiventris* Hall from Nevada. J. Mammal. 38(2): 267; 1957.

Chattin, J. E. The distribution of pocket gophers in southeastern Calif. San Diego Society of Natural History, Transactions 9(27): 265-284; 1941.

Cleveland, A. G. 1st South Texas USA records of *Pappogeomys castanops*. Tex. J. Sci. 29(3/4): 299; 1977.

Colorado Cooperative Pocket Gopher Project. Pocket gophers in Colorado. Bull. 508-S. Fort Collins, CO: Colorado State University, Agriculture Experiment Station; 1960. 26 p.

Coues, E. Synopsis of the Geomyidae. Philadelphia Academy of Natural Science, Proceedings 27: 130-138; 1875.

Dalquest, W. W.; Kilpatrick, W. Dynamics of pocket gopher distribution on the Edwards Plateau of Texas. Southwest Nat. 18(1): 1-9; 1973.

Dalquest, W. W.; Scheffer, V. B. Distribution and variation in pocket gophers, *Thomomys talpoides* in the state of Washington. Am. Nat. 78: 308-333, 423-450; 1944.

Davis, W. B. Critical notes on the pocket gophers of Texas. J. Mammal. 19(4): 488-490; 1938.

Davis, W. B. Distribution and variation of pocket gophers. (Genus *Geomys*) in the southwestern United States. Bull. No. 590. College Station, TX: Texas Agricultural Experiment Station; 1940. 38 p.

Davis, W. B. Substitute name for *Geomys personatus minor* Davis. J. Mammal. 24(4): 508; 1943.

Davis, W. B.; Buechner, H. K. Pocket gophers (*Thomomys*) of the Davis Mountains, Texas. J. Mammal. 27(3): 265-271; 1946.

Davis, W. H. Northern extension of range of pocket gophers east of the Mississippi. J. Mammal. 36(1): 142-143; 1955.

DeMott, D. L.; Lindsey, G. P. Pygmy shrew *Microsorex hoyi* in Gunnison County, Colorado USA. Southwest Nat. 20(3): 417-418; 1975.

Downhower, J. F.; Hall, E. R. The pocket gopher in Kansas. Misc. Publ. No. 44. Lawrence, KS: University of Kansas, Museum of Natural History; 1966. 32 p.

Drake, H.; Booth, E. S. Revisions of the ranges of the pocket gophers of southeastern Washington and northeastern Oregon and the description of a new subspecies *Thomomys talpoides whitmani*. College Place, WA: Walla Walla College, Department of Biological Science and Biology Station, Publ. 1(3): 44-58; 1952.

Durrant, S. D. Two new gophers from Utah. University of Utah Bull. 28(4): 1-6; 1937. (Biol. Ser. Vol. 3, No. 8).

Durrant, S. D. A new pocket gopher of the *Thomomys quadratus* group from the northern Great Basin region. University of Utah Bull. 29(6): 1-6; 1939. (Biol. Ser. Vol. 3, No. 10).

Durrant, S. D. Two new gophers (Mammalian Genus *Thomomys*) from western Utah. Biological Society of Washington, Proceedings 52: 159-162; 1939.

Durrant, S. D. The pocket gophers (Genus *Thomomys*) of Utah. Univ. Kans., Mus. Nat. Hist., Publ. 1: 1-82; 1946.

Feldhamer, G. A. Vegetative and edaphic factors affecting abundance and distribution of small mammals in southeast Oregon USA. Great Basin Nat. 39(3): 207-218; 1979.

Gabrielson, I. N. Notes on *Thomomys* in Oregon. J. Mammal. 4: 189-190; 1923.

Ghiselin, J. *Thomomys bottae* in Granite Springs Valley, Pershing County, Nevada. J. Mammal. 46(3): 525; 1965.

Glass, B. P. Ecological factors affecting distribution and speciation of pocket gophers in Oklahoma. Stillwater, OK: Oklahoma State University; 1952. Dissertation.

Goldman, E. A. New pocket gophers from Arizona and Utah. Wash. Acad. Sci. J. 21(17): 416-426; 1931.

Goldman, E. A. New pocket gophers of the genus *Thomomys*. Wash. Acad. Sci. J. 26(3): 111-120; 1936.

Goldman, E. A. New pocket gophers of the genus *Thomomys* from Arizona and Utah. Wash. Acad. Sci. J. 28(7): 333-343; 1938.

Goldman, E. A. The systematic status of certain pocket gophers with special reference to *Thomomys monticola*. Wash. Acad. Sci. J. 33(5): 146-147; 1943.

Goldman, E. A. The pocket gophers (Genus *Thomomys*) of Arizona. North American Fauna 59. Washington, DC: U.S. Department of the Interior, Fish and Wildlife Service; 1947. 39 p.

Grinnell, J. Geography and evolution in the pocket gopher. Berkeley, CA: University of California Chronicle; 1926: 247-262.

Grinnell, J. The pocket gopher of the Honey Lake Valley. Univ. Calif. Publ. Zool. 30: 1-6; 1926.

Grinnell, J. A new pocket gopher from Lassen County, California. Biological Society of Washington, Proceedings 47: 193-198; 1934.

Grinnell, J.; Swarth, H. S. The pocket gopher of the boreal zone on San Jacinto Peak. California Academy of Science, Proceedings 4(6): 153-160; 1914.

Hall, E. R. New pocket gophers from Nevada. Univ. Calif. Publ. Zool. 38(4): 325-333; 1932.

Hall, E. R. Three new pocket gophers from New Mexico and Arizona. Biological Society of Washington, Proceedings 45: 95-98; 1932.

Hall, E. R. A new pocket gopher (Genus *Thomomys*) from eastern Colorado. Univ. Kans., Mus. Nat. Hist., Publ. 5: 81-85, 1951.

Hansen, R. M.; Vaughan, T. A.; Hervey, D. F.; (and others). Pocket gophers in Colorado. Bull. 508-S. Fort Collins, CO: Colorado State University, Agriculture Experiment Station; 1960. 26 p.

Hansen, R. M.; Reid, V. H. Distribution and adaptations of pocket gophers. In: Pocket gophers and Colorado mountain rangeland. Bull. 554-S. Fort Collins, CO: Colorado State University, Agriculture Experiment Station; 1973: 1-19.

Harper, R. M. Notes on the distribution of the southeastern salamanders (*Geomys tuza* and allies). Science. 35: 115-119; 1912.

Harrison, J. A. Mammals of the wolf range local fauna pliocene of the San Pedro Valley, Arizona USA. Occ. Pap. 78. Lawrence, KS: University of Kansas, Museum of Natural History; 1978: 1-18.

Hooper, E. T. New pocket gophers from the vicinity of Mount Taylor, New Mexico. Occ. Pap. No. 422. Ann Arbor, MI: University of Michigan, Museum of Zoology; 1940. 13 p.

Hooper, E. T. A new race of pocket gopher of the species *Geomys lutescens* from Colorado. Occ. Pap. No. 420. Ann Arbor, MI: University of Michigan, Museum of Zoology; 1940. 3 p.

Hooper, E. T. Type localities of pocket gophers of the genus *Thomomys*. Misc. Publ. No. 58. Ann Arbor, MI: University of Michigan, Museum of Zoology; 1941. 26 p.

Hooper, E. T. Two genera of pocket gophers should be congeneric. J. Mammal. 27(4): 397-399; 1946.

Ingles, L. G. Family Geomyidae and the key to pocket gophers. In: Ingles, L. G. Mammals of the Pacific States. Stanford, CA: Stanford University Press; 1965: 201-211.

Ingles, L. G.; Biglione, N. J. The contiguity of the ranges of two subspecies of pocket gophers. Evolution 6(2): 204-207; 1952.

Johnson, M. L.; Benson, S. B. Relationship of the pocket gophers of the *Thomomys mazama talpoides* complex in the Pacific Northwest. Murrelet 41: 17-22; 1960.

Johnstone, W. B. A revision of the pocket gopher *Thomomys talpoides* in British Columbia. Can. Field-Nat. 68(4): 155-164; 1954.

Kelson, K. R. Two new subspecies of *Thomomys bottae* from New Mexico and Colorado. Univ. Kans., Mus. Nat. Hist., Publ. 5: 59-71; 1951.

Kennerly, T. E., Jr. Local differentiation in the pocket gopher *Geomys personatus* in southern Texas. Texas J. Sci. 6(3): 297; 1954.

Kennerly, T. E., Jr. Contact between the ranges of two allopatric species of pocket gophers. Evolution. 13: 247-263; 1959.

Kilby, J. D. The name salamander for the pocket gophers. J. Mammal. 16(4): 326-327; 1935.

Komarek, E. V.; Spencer, D. A. A new pocket gopher from Illinois and Indiana. J. Mammal. 12(4): 404-408; 1931.

LeConte, J. L. An attempt at a synopsis of the genus *Geomys rafinesque*. Philadelphia Academy of Natural Science, Proceedings 6: 157-163; 1852.

Lyon, M. W., Jr. Remarks on *Geomys bursarius illinoensis* Komarek and Spencer. J. Mammal. 13(1): 77-78; 1932.

Madsen, C. R. Florida pocket gopher (Salamander). Circ. 310. Gainesville, FL: Florida University Extension; 1967. 12 p.

Mares, M. A. Convergent evolution among desert rodents, a global perspective. Andrew Carnegie Museum of Natural History Bull. 16: 5-51; 1979.

Matson, J. O. The distribution of rodents in Owens Lake Region, Inyo County, California USA. Contributions in Science No. 276. Los Angeles, CA: Natural History Museum of Los Angeles County; 1976. 27 p.

McLaughlin, C. A. A taxonomic study of the pocket gophers, genus *Geomys* of the central United States. Urbana, IL: University of Illinois; 1958. 298 p. Thesis.

Mearns, E. A. The earliest systematic name of the tuoza, or Georgia pocket gopher. Biological Society of Washington, Proceedings 27: 102; 1914.

Merriam, C. H. Monographic revision of the pocket gophers, family Geomyidae (exclusive of the species of *Thomomys*). North American Fauna No. 8. Washington, DC: U.S. Department of Agriculture, Bureau of Biological Survey; 1895. 258 p.

Merriam, C. H. Descriptions of eight new pocket gophers of the genus *Thomomys* from Oregon, California, and Nevada. Biological Society of Washington, Proceedings 11: 213-216; 1897.

Merriam, C. H. Descriptions of twenty-three new pocket gophers of the genus *Thomomys*. Biological Society of Washington, Proceedings 14: 107-117; 1901.

Merriam, C. H. Monographic revision of the pocket gophers, family Geomyidae exclusive of the species of *Thomomys*. North American Fauna 8. Washington, DC: U.S. Department of Agriculture, Bureau of Biological Survey; 1906. 262 p.

Miller, R. S. Ecology and distribution of pocket gophers (Geomyidae) in Colorado. Ecology. 45(2): 256-272; 1964.

Mitchill, S. L. Detection of a mistake into which naturalists have been led, in relation to the *Mus bursarius* or pouched rat of Canada. Am. J. Sci. and Arts 4: 183-185; 1822.

Mohr, C. O. Distribution of the Illinois pocket gopher, *Geomys bursarius illinoensis*. J. Mammal. 16(2): 131-134; 1935.

Mohr, C. O. Distribution of the prairie mole and pocket gopher in Illinois. J. Mammal. 27(4): 390-392; 1946.

Moulton, M. P.; Choate, J. R.; Bissell, S. J. Sympatry of pocket gophers on Mesa De Maya, Colorado USA. Kansas Academy of Science, Transactions 82(3): 194-195; 1979.

Nelson, E. W.; Goldman, E. A. Revision of the pocket gophers of the genus *Cratogeomys*. Biological Society of Washington, Proceedings 47: 135-154; 1934.

Patton, J. L. An analysis of natural hybridization between the pocket gophers *Thomomys bottae* and *Thomomys umbrinus* in Arizona. J. Mammal. 54(3): 561-584; 1973.

Pittman, H. H. The prairie pocket gopher in Manitoba. Can. Field-Nat. 40(3): 60-62; 1926.

Quimby, D. *Thomomys* in Minnesota. J. Mammal. 23: 216-217; 1942.

Reichman, O. J.; Baker, R. J. Distribution and movements of two species of pocket gophers (Geomyidae) in an area of sympatry in the Davis Mountains, Texas. J. Mammal. 53: 21-33; 1972.

Rensberger, J. M. Sanctimum mammalia rodentia and the phyletic relationships of the large Arikareean geomyoids. J. Paleontol. 47(5): 835-853; 1973.

Russell, R. J. Evolution and classification of pocket gophers of the subfamily Geomyinae. Univ. Kans., Mus. Nat. Hist., Publ. 16(6): 473-579; 1968a.

Russell, R. J. Revision of pocket gophers of the genus *Pappogeomys*. Univ. Kans., Mus. Nat. Hist., Publ. 16(7): 581-776; 1968b.

Russell, R. J.; Baker, R. H. Geographic variation in the pocket gopher *Cratogeomys castanops* in Coahuila, Mexico. Univ. Kans., Mus. Nat. Hist., Publ. 7(12): 591-608; 1955.

Sands, J. L.; Findley, J. S. The relationships of two subspecies of pocket gophers in central New Mexico. J. Mammal. 40(30): 331-337; 1959.

Sherman, H. B. A new species of pocket gopher (*Geomys*) from eastern Georgia. J. Mammal. 21(3): 341-343; 1940.

Soper, J. D. The Mississippi Valley pocket gopher (*Geomys bursarius* Shaw) in Manitoba. Can. Field-Nat. 58(3): 71-72; 1944.

Storer, T. I.; Evans, F. C.; Palmer, F. G. Some rodent populations in the Sierra Nevada of California. Ecol. Monogr. 14: 165-192; 1944.

Taylor, W. P. A new pocket gopher from western Washington. Biological Society of Washington, Proceedings 32: 169-172; 1914.

Thornton, W. A.; Creel, G. C. Distribution of gophers Geomyidae in western Texas. Southwest Nat. 20(2): 272-275; 1975.

True, F. W. Description of *Geomys personatus* and *Dipodomys compactus*, two new species of rodents from Padre Island, Texas. U.S. National Museum, Proceedings 11: 159-160; 1888.

Vaughan, T. A. Two parapatric species of pocket gophers. Evolution. 21: 148-158; 1967.

Villa-Ramirez, B.; Hall, E. R. Subspeciation in pocket gophers of Kansas. Univ. Kans., Mus. Nat. Hist., Publ. 1(11): 217-236; 1947.

Walker, K. M. Distribution and life history of the black pocket gopher *Thomomys niger* (Merriam). Corvallis, OR: Oregon State University; 1949. M.S. thesis.

Walker, K. M. Distribution and taxonomy of the small pocket gophers of northwestern Oregon. Corvallis, OR: Oregon State University; 1955. 200 p. Dissertation.

Wight, H. M. Pocket gophers of Oregon. Oregon Countryman. 12(7): 18; 1920.

Wight, H. M. The Willamette Valley pocket gopher. Murrelet. 3(3): 6-8; 1922.

Williams, S. L.; Blake, R. J. *Geomys arenarius*. Mammal. Species. 36: 1-3; 1974.

Wood, A. E. Parallel radiation among the geomyoid rodents. J. Mammal. 18: 171-176; 1937.

Youngman, P. M. Geographic variation in the pocket gopher, *Thomomys bottae*, in Colorado. Univ. Kans., Mus. Nat. Hist., Publ. 9: 363-384; 1958.

Predators and Mortality (PM)

Ambrose, H. W. Effect of habitat familiarity and toe-clipping on rate of owl predation in *Microtus pennsylvanicus*. J. Mammal. 53(4): 909-912; 1972.

Arnold, L. W. The golden eagle and its economic status. Circ. 27. Washington, DC: U.S. Department of the Interior, Fish and Wildlife Service; 1954. 35 p.

Bailey, T. M. Ecology of bobcats with special reference to social organization. Moscow: University of Idaho; 1972. 85 p. Dissertation.

Bent, A. C. Life histories of North American birds of prey, part I. Bull. No. 167. Washington, DC: U.S. National Museum, Smithsonian Institution; 1937. 409 p.

Bent, A. C. Life histories of North American birds of prey, part II. Bull. No. 170. Washington, DC: U.S. National Museum, Smithsonian Institution; 1938. 482 p.

Bird, R. D. The great horned owl in Manitoba. Can. Field-Nat. 43(4): 79-83; 1929.

Bond, R. M. Coyote food habits on the Lava Beds National Monument. J. Wildl. Manage. 3(3): 180-198; 1939.

Brown, L. H.; Watson, A. The golden eagle in relation to its food supply. Ibis. 106(1): 78-100; 1964.

Craig, T. H.; Trost, C. H. The biology and nesting density of breeding American kestrels and long-eared owls on the Big Lost River, southeastern Idaho USA. Wilson Bull. 91(1): 50-61; 1979.

Craighead, J. J.; Craighead, F. C., Jr. Hawks, owls, and wildlife. Harrisburg, PA: Stackpole; 1956. 443 p.

Dixon, J. Food predilections of predatory and furbearing mammals. J. Mammal. 6(1): 34-46; 1925.

Egoscue, H. J. Ecology and life history of the kit fox in Tooele County, Utah. Ecology. 43(3): 481-497; 1962.

English, P. F. Some observations on a pair of red-tailed hawks. Wilson Bull. 46(4): 228-235; 1934.

Errington, P. L. Food habits of southern Wisconsin raptors. Part III: hawks. Condor. 35: 19-29; 1933.

Errington, P. L. Of predation and life. Ames, IA: Iowa State University Press; 1967. 277 p.

Evans, F. C.; Emlen, J. T., Jr. Ecological notes on the prey selected by a barn owl. Condor. 49(1): 3-9; 1947.

Fassler, D. J. Terrestrial activity of the northern pocket gopher Geomyidae is indicated by owl predation. Southwest Nat. 19(4)L: 452-453; 1975.

Ferrel, C. M.; Leach, H. R.; Tillotson, D. F. Food habits of the coyote in California. Calif. Fish and Game 39(3): 301-341; 1953.

Fevold, H. R.; Craighead, J. J. Food requirements of the golden eagle. Auk. 75(3): 312-317; 1958.

Fichter, E.; Schildman, G.; Sather, J. H. Some feeding patterns of coyotes in Nebraska. Ecol. Monogr. 25(1): 1-37; 1955.

Fitch, H. S. Some observations on horned owl nests. Condor. 42: 73-75; 1940.

Fitch, H. S. Predation by owls in the Sierra foothills of California. Condor. 49: 137-151; 1947.

Fitch, H. S. A study of coyote relationships on cattle range. J. Wildl. Manage. 12(1): 73-78; 1948.

Fitch, H. S. Study of snake populations in central California. Am. Midl. Nat. 41(3): 513-579; 1949.

Fitch, H. S.; Swenson, F.; Tillotson, D. F. Behavior and food habits of the red-tailed hawk. Condor. 48: 205-237; 1946.

Fitch, H. S.; Twining, H. Feeding habits of the Pacific rattlesnake. Copeia. 2: 64-71; 1946.

Fitzner, R. E.; Berry, D.; Boyd, L. L.; Rieck, C. A. Nesting of ferruginous hawks (*Buteo ragalis*) in Washington 1974-1975. Condor. 79(2): 245-249; 1977.

Gashwiler, J. S.; Robinette, W. L.; Morris, O. W. Foods of bobcats in Utah and Nevada. J. Wildl. Manage. 24(2): 226-229; 1960.

Gloyd, H. K. Field studies of the diurnal raptors of eastern and central Kansas. Wilson Bull. 37(3): 133-149; 1925.

Grater, R. K. Coyote food habits near Boulder (Hoover) Dam. J. Wildl. Manage. 7(4): 422-423; 1943.

Hawthorne, D. M. Coyote food habits in Sagehen Creek Basin, Northeastern California. Calif. Fish and Game 58(1): 4-12; 1972.

Hisaw, F. L.; Gloyd, H. K. The bullsnake as a natural enemy of injurious rodents. J. Mammal. 7(3): 200-205; 1926.

Imler, R. H. Bullsnakes and their control on a Nebraska wildlife refuge. J. Wildl. Manage. 9(40): 265-273; 1945.

Jones, J. H.; Smith, N. S. Bobcat (*Lynx rufus*) density and prey selection in central Arizona, USA. J. Wildl. Manage. 43(3): 666-672; 1979.

Kalmbach, E. R.; Imler, R. H.; Arnold, L. W. The American eagles and their economic status. Washington, DC: U.S. Department of the Interior, Fish and Wildlife Service; 1964. 88 p.

Knowlton, F. F. Aspects of coyote predation in south Texas with special reference to white-tailed deer. Lafayette, In: Purdue University; 1964. 208 p. Dissertation.

Korschgen, L. J. Food habits of the red fox in Missouri. J. Wildl. Manage. 23(2): 168-176; 1959.

Luttich, S.; Rusch, D. H.; Meslow, E. C.; Keith, L. B. Ecology of red-tailed hawk predation in Alberta. Ecology. 51(2): 190-203; 1970.

Marston, M. A. Winter relations of bobcats to white-tailed deer in Maine. J. Wildl. Manage. 6(4): 328-337; 1942.

Marti, C. D. Some comparisons of the feeding ecology of four owls in northcentral Colorado. Southwest. Nat. 14(2): 163-170; 1969.

Marti, C. D.; Braun, C. E. Use of tundra habitats by prairie falcons in Colorado, USA. Condor. 77: 213-214; 1975.

Maser, C.; Brodie, E. D., Jr. A study of owl pellet contents from Linn, Benton and Polk Counties, Oregon. Murrelet. 47(1): 9-14; 1966.

Maser, C.; Hammer, E. W.; Anderson, S. H. Food habits of the burrowing owl in central Oregon. Northwest Sci. 45(1): 19-26; 1971.

McAtee, W. L. Food habits of common hawks. Circ. No. 370. Washington, DC: U.S. Department of Agriculture; 1935. 36 p.

McGahan, J. Quantified estimates of predation by a golden eagle population. J. Wildl. Manage. 31(3): 496-501; 1967.

McGahan, J. Ecology of the golden eagle. Auk. 85(1): 1-12; 1968.

McLean, D. D. Predatory animal studies. Calif. Fish and Game 20(1): 30-36; 1934.

Mech, L. D. The wolf: the ecology and behavior of an endangered species. Garden City, NY: The Natural History Press; 1970. 384 p.

Meslow, E. C.; Keith, L. B. Summer food habits of red-tailed hawks near Rochester, Alberta. Can. Field-Nat. 80(2): 98-100; 1966.

Metzgar, L. H. An experimental comparison of screech owl predation on resident and transient white-footed mice (*Peromyscus leucopus*). J. Mammal. 48(3): 378-391; 1967.

Mollhagen, T. R.; Wiley, R. W.; Packard, R. L. Prey remains in golden eagle nests: Texas and New Mexico. J. Wildl. Manage. 36(3): 784-792; 1972.

Moore, J. C. Life history notes on the Florida weasel. Fla. Acad. Sci., Quar. J. 7(4): 247-263; 1945.

Morse, A. P. The way of a snake with a gopher. Copeia. 16(4): 71-72; 1927.

Murie, A. Ecology of the coyote. National Park Service Fauna Series 4. Washington, DC: U.S. Department of the Interior, National Park Service; 1940. 199 p.

Murie, A. Ecology of the coyotes in the Yellowstone. Fauna of the National Parks of the U.S. Bull. 4. Washington, DC: U.S. Department of the Interior, National Park Service; 1940. 206 p.

Murie, O. J. Food habits of the coyote in Jackson Hole, Wyoming. Circ. 362. Washington, DC: U.S. Department of Agriculture; 1935. 24 p.

Ogle, T. F. Predator-prey relationships between coyotes and white-tailed deer. Northwest Sci. 45(4): 213-218; 1971.

Orians, G.; Kuhlman, F. Red-tailed hawk and great horned owl populations in Wisconsin. Condor. 58: 371-385; 1956.

Ozoga, J. J.; Harger, E. J. Winter activities and feeding habits of northern Michigan coyotes. J. Wildl. Manage. 30(4): 809-818; 1966.

Pearson, O. P.; Pearson, A. K. Owl predation in Pennsylvania with notes on the small mammals of Delaware County. J. Mammal. 28: 137-147; 1947.

Pfeifer, R. W. Great blue herons (*Ardea herodias*) foraging for small mammals. Wilson Bull. 91(4): 630-631; 1979.

Reid, V. H. Population biology of the northern pocket gopher. Bull. 554S. Fort Collins, CO: Colorado State University, Agriculture Experiment Station; 1973: 21-41.

Ribic, C. A. Summer foods of coyotes at Rocky Flats, Colorado USA. Southwest Nat. 23(1): 152-153; 1978.

Rickart, E. A. An analysis of barn owl and great horned owl pellets from western Nebraska USA. Prairie Nat. 4(2): 35-38; 1972.

Robinson, W. B. Population trends of predators and fur animals in 1080 station areas. J. Mammal. 34: 221-227; 1953.

Robinson, W. B. Population changes of carnivores in some coyote-control areas. J. Mammal. 42(4): 510-515; 1961.

Scott, T. G. Some food co-actions of the northern plains red fox. Ecol. Monogr. 13(4): 427-479; 1943.

Seton, E. T. Lives of game animals, vol. V. Garden City, NY: Doubleday; 1929.

Smith, C. F.; Hopkins, C. L. Notes on the barn owls of the San Francisco Bay region. Condor. 39: 189-191; 1937.

Snead, E.; Hendrickson, G. O. Food habits of the badger in Iowa. J. Mammal. 23(4): 380-391; 1942.

Sparrowe, R. D. Prey-catching behavior in the sparrow hawk. J. Wildl. Manage. 36(2): 297-308: 1972.

Sperry, C. C. Food habits of the coyote. Wildl. Res. Bull. 4. Washington, DC: U.S. Department of the Interior, Fish and Wildlife Service; 1941. 70 p.

Stendell, R. C.; Myers, P. White-tailed kite predation on a fluctuating vole population. Condor. 75(3): 359-360; 1973.

Tryon, C. A., Jr. The great grey owl as a predator on pocket gophers. Wilson Bull. 55(2): 130-131; 1943.

Wakeley, J. S. Activity periods, hunting methods, and efficiency of the ferruginous hawk. Raptor Res. 8(3/4): 67-72; 1974.

Weckwerth, R. P.; Hawley, V. D. Marten food habits and population fluctuations in Montana. J. Wildl. Manage. 26(1): 55-74; 1962.

Williams, S. L. Effect of floods on *Thomomys bottae* in Texas USA. Southwest Nat. 21(2): 169-175; 1976.

Wood, J. E. Food habits of furbearers of the upland post oak region in Texas. J. Mammal. 35(3): 406-415; 1954.

Young, S. P. The bobcat of North America. Harrisburg, PA: Stackpole; 1958. 193 p.

Young, S. P.; Jackson, H. T. The clever coyote: part I and part II. Harrisburg, PA: Stackpole; 1951. 411 p.

Movements (M)

Adams, Glen D. Populations and spatial distribution of pocket gophers (*Geomys bursarius*). Ann Arbor, MI: University of Michigan; 1966. 136 p. Dissertation.

Hansen, R. M. Movements and survival of *Thomomys talpoides* in a mima-mound habitat. Ecology. 43(1): 151-154; 1962.

Ingles, L. G. Ground water and snow as factors affecting the seasonal distribution of pocket gophers, *Thomomys monticola*. J. Mammal. 30(4): 343-350; 1949.

Vaughan, T. A. Movements made by two species of pocket gophers. Am. Midl. Nat. 69(2): 367-372; 1963.

Fluctuations (F)

Aldous, C. M. Fluctuations in pocket gopher populations. J. Mammal. 38(2): 266-267; 1957.

Andersen, D. C.; MacMahon, J. A. Population dynamics and bioenergetics of a fossorial herbivore, *Thomomys talpoides* (Rodentia:Geomyidae), in a spruce-fir sere. Ecol. Monogr. 51: 179-202; 1981.

Blair, W. F. Some observed effects of stream-valley flooding on mammalian populations in eastern Oklahoma. J. Mammal. 29(2): 304-306; 1939.

Blair, W. F. Population dynamics of rodents and other small mammals. In: Demerec, M., ed. Advances in genetics, vol. 5. New York: Academic Press; 1953: 1-41.

Dingman, R. E. Variation in selected populations of pocket gophers (*Thomomys bottae*) of the Lower Colorado River. Tucson, AZ: University of Arizona; 1966. 134 p. Dissertation.

Hansen, R. M. Pocket gopher density in an enclosure of native habitat. J. Mammal. 46(3): 508-509; 1965.

Hansen, R. M.; Bear, G. D. Comparison of pocket gophers from alpine, sub-alpine and shrub-grassland habitats. J. Mammal. 45(4): 638-640; 1964.

Hansen, R. M.; Remmenga, E. E. Nearest neighbor concept applied to pocket gopher populations. Ecology. 42(4): 812-814; 1961.

Howard, W. E. A pocket gopher population crash. J. Mammal. 42(2): 258-260; 1961.

Mohr, C. O. Table of equivalent populations of North American small mammals. Am. Midl. Nat. 37(1): 223-249; 1947.

Proctor, J.; Whitten, K. A population of the valley pocket gophers (*Thomomys bottae*) on a serpentine soil. Am. Midl. Nat. 85(2): 517-521; 1971.

Reid, V. H. Response of small mammal populations to various intensities of livestock grazing in the southern Rocky Mountains Region. Denver, CO: Denver Wildlife Research Center; 1962. 36 p. Annual progress report (mimeo).

Reid, V. H. Small mammal populations in relation to grazing on Black Mesa. Denver, CO: Denver Wildlife Research Center, Wildlife Research Work Unit; 1966. 17 p. Annual progress report.

Reid, V. H. Small mammal populations in relation to grazing on Black Mesa. Denver, CO: Denver Wildlife Research Center, Wildlife Research Work Unit; 1967. 14 p. Annual progress report.

Thaeler, C. S., Jr. An analysis of three hybrid populations of pocket gophers. Evolution. 22(3): 543-555; 1968.

Wilks, B. J. Some aspects of the ecology and population dynamics of the pocket gopher (*Geomys bursarius*) in southern Texas. Texas J. Sci. 15(3): 241-283; 1963.

Natural History (NH)

Allen, M. C. Gophers and squirrels. Calif. Cultivator. 43: 66; 1914.

Blume, R. R.; Aga, A. Additional records of *Aphoidius* from pocket gopher burrows in Texas (Coleoptera:Scarabaeidae). The Coleopterists Bull. 33(1): 131-132; 1979.

Burnett, W. L. Pocket gophers. Circ. 10. Fort Collins, CO: Office of State Entomology; 1914. 8 p.

Criddle, S. The prairie pocket gopher, *Thomomys talpoides rufescens*. J. Mammal. 11(3): 265-280; 1930.

Frandsen, J. C.; Grundmann, A. W. The history of some subspecies of pocket gophers as told by their monoxenous nematodes. Utah Academy of Science, Arts, and Letters, Proceedings 37: 154-155; 1960.

Goldman, E. A. Remarks on pocket gophers with special reference to *Thomomys talpoides*. J. Mammal. 20(2): 231-244; 1939.

Hansen, R. M.; Vaughan, T. A. Plains pocket gopher studies. Progress Report 164. Fort Collins, CO: Colorado State University, Agriculture Experiment Station; 1965. 2 p.

Hart, E. B. Karyology and evolution of the plains pocket gopher *Geomys bursarius*. Occ. Pap. No. 71. Lawrence, KS: University of Kansas, Museum of Natural History; 1978. 19 p.

Hegdal, P. L.; Ward, A. L.; Johnson, A. M.; Tietjen, H. P. Notes on the life history of the Mexican pocket gopher (*Cratogeomys castanops*). J. Mammal. 46(2): 334-335; 1965.

Howard, W. E. The pesky pocket gopher. Spreckles Sugar Beet Bull. 16(3): 21-22; 1952.

Howard, W. E.; Ingles, L. G. Outline for an ecological life history of pocket gophers and other fossorial mammals. Ecology. 32(3): 537-544; 1951.

Kennerly, T. E., Jr. Comparisons of morphology and life history of two species of pocket gophers. Texas J. Sci. 10(2): 133-146; 1958.

Lidicker, W. Z., Jr. Corrections and additions to our knowledge of the pocket gopher. Murrelet. 52(1): 12-13; 1971.

Long, C. A. Evolution of mammalian cheek pouches and a possibly discontinuous origin of a higher taxon Geomyidae. Am. Nat. 110(976): 1093-1097; 1976.

Newman, C. L. The pocket gopher (*Geomys breviceps*). Ark. Agric. Exp. Stn. Bull. 28: 108-112; 1894.

Pembleton, E. F.; Williams, S. L. *Geomys pinetis*. Mamm. Species. 86: 1-3; 1978.

Randall, W. A. Gophers. Calif. Cultivator. 44: 279; 1915.

Russell, R. J. A multiple catch of *Cratogeomys*. J. Mammal. 35(1): 121-122; 1954.

Sagal, B. E. Natural history of the pocket gopher, *Thomomys bottae*, of Alameda County, Calif. Berkeley: University of California; 1942. 92 p. Thesis.

Scheffer, T. H. The pocket gopher. Bull. 152. Lawrence, KS: Kansas Agriculture Experiment Station; 1908: 111-145.

Scheffer, T. H. The pocket gopher. Bull. 172. Lawrence, KS: Kansas Agriculture Experiment Station; 1910: 197-234.

Scheffer, T. H. Concerning the pocket gopher in mole range. Circ. 242. Pullman, WA: Washington Agricultural Experiment Station; 1954. 4 p.

Scott, W. F. Moles and gophers. Am. Iris Soc. Bull. 141: 13-16; 1956.

Shufeldt, R. W. The gophers and pouched rats. Forest and Stream. 31(14): 263-264; 1888.

Taylor, W. P. Outlines for study of mammalian ecology and life histories. Leaflet 304. Washington, DC: U.S. Department of the Interior, Fish and Wildlife Service; 1948: 1-26.

Tryon, C. A., Jr. The biology of the pocket gopher (*Thomomys talpoides*) in Montana. Tech. Bull. 448. Bozeman, MT: Montana Agricultural Experiment Station; 1947. 30 p.

Tryon, C. A.; Cunningham, H. N. Characteristics of pocket gophers along an altitudinal transect. J. Mammal. 49(4): 699-705; 1968.

Walker, K. M. Distribution and life history of the black pocket gopher *Thomomys niger* (Merriam). Corvallis, OR: Oregon State University; 1949. Thesis.

Warren, E. R. Notes on pocket gophers. J. Mammal. 18(4): 473-477; 1937.

Washburn, F. L. Gophers and rabbits. Oreg. Agric. Exp. Stn. Bull. 5: 24-29; 1980.

Washburn, F. L. Gophers and moles. Oreg. Agric. Exp. Stn. Bull. 125: 14-24; 1893.

Washburn, F. L. Pocket gopher and "digger squirrel." Oreg. Agric. Exp. Stn. Bull. 38: 13-15; 1895.

Watson, J. R. "Salamanders" and "gophers." Bull. 609. Gainesville, FL: Florida Agriculture Experiment Station; 1945. 4 p.

Webster, C. L. The pocket or pouched gopher (*Geomys bursarius*). Am. Nat. 31: 114-120; 1897.

Wight, H. M. The life history and control of the pocket gopher in the Willamette Valley. Bull. 153. Corvallis, OR: Oregon Agriculture Experiment Station; 1918. 55 p.

Williams, S. L.; Genoways, H. H. Review of the desert pocket gopher *Geomys arenarius* Mammalia:Rodentia. Andrew Carnegie Mus. Nat. Hist. Bull. 47(23): 541-570; 1978.

Yocum, H. B. The pocket gopher. Circ. 43. Lawrence, KS: Kansas Agriculture Experiment Station; 1915. 4 p.

Physiology and Morphology (PHM)

Andersen, D. C.; MacMahon, J. A.; Wolfe, M. L. Herbivorous mammals along a montane sere; community structure and energetics. J. Mammal. 61: 500-519; 1980.

Akersten, W. A. Upper incisor grooves in the Geomyinae. J. Mammal. 54(2): 349-355; 1973.

Benson, S. B. Concealing coloration among some desert rodents of the southwestern United States. Univ. Calif. Publ. Zool. 40(1): 1-70; 1933.

Bongardt, H.; Richens, V. C.; Howard, W. E. Serum protein patterns in pocket gophers. J. Mammal. 49(3): 544-547; 1968.

Bradley, W. G. An albino pocket gopher. J. Mammal. 44(2): 261; 1963.

Bradley, W. G.; Miller, J. S.; Yousef, M. K. Thermo regulatory patterns in pocket gophers desert and mountain. Physiol. Zool. 47(3): 172-179; 1974.

Bradley, W. G.; Yousef, M. K. Thermo regulation in the Plains pocket gopher. J. Ariz. Acad. Sci. 9: Supplement; 1974. 18 p.

Bradley, W. G.; Yousef, M. K. Thermo regulatory responses in the Plains pocket gopher *Geomys bursarius*. Comp. Biochem. Physiol. A. Comp. Physiol. 52(1): 35-38; 1975.

Brown, J. C.; Williams, J. D. The rodent preputial gland. Mammal. Rev. 2(4): 105-147; 1972.

Burt, W. H. Bacula of North American mammals. Misc. Publ. 113. Ann Arbor, MI: University of Michigan, Museum of Zoology; 1960. 100 p.

Coues, E. The cranial and dental characters of Geomyidae. U.S. Geol. and Geogr. Surv. Terr. 2nd ser. Bull. 2: 81-90; 1875.

Dahlman, R. C.; Kucera, C. L. Root productivity and turnover in native prairie. Ecology. 46: 84-89; 1965.

Davis, W. B. Relation of size of pocket gophers to soil and altitude. J. Mammal. 19: 338-342; 1938.

Fehrenbacher, L. H.; Fleharty, E. D. Body composition, energy content and lipid cycles of 2 species of pocket gophers *Geomys bursarius* and *Pappogeomys castanops* in Kansas. Southwest Nat. 21(2): 185-198; 1976.

French, N. R.; Grant, W. E.; Grodzinski, W.; Swift, D. M. Small mammal energetics in grassland ecosystems. Ecol. Monogr. 46: 201-220; 1976.

Gettinger, R. D. Metabolism and thermo regulation of a fossorial rodent, the northern pocket gopher *Thomomys talpoides*. Physiol. Zool. 48(4): 311-322; 1975.

Getz, L. L. Color variation in pocket gophers *Thomomys*. J. Mammal. 38(4): 523-526; 1957.

Guthrie, D. A.; DeLong, N. Carotid arteries in the rodent genera *Pappogeomys, Geomys* and *Thomomys* family Geomyidae. South. Calif. Acad. Sci. Bull. 76(1): 63-66; 1977.

Hill, J. E. External characteristics of newborn pocket gophers. J. Mammal. 15: 244-245; 1934.

Hill, J. E. The cranial foramina in rodents. J. Mammal. 16(2): 121-128; 1935.

Hill, J. E. The retractor muscle of the pouch in the Geomyidae. Science. 81(2093): 160; 1935.

Hill, J. E. Morphology of the pocket gopher mammalian genus *Thomomys*. Univ. Calif. Publ. Zool. 42: 81-172; 1937.

Hisaw, F. L. The absorption of the pubic symphysis of the pocket gopher, *Geomys bursarius* (Shaw). Am. Nat. 58(654): 93-96; 1924.

Hisaw, F. L. The influence of the ovary on the resorption of the pubic bones of the pocket gopher *Geomys bursarius* (Shaw). J. Explor. Zool. 42: 411-433; 1925.

Hollinger, C. D. Anatomical adaptations in the thoracic limb of the California pocket gopher and other rodents. Univ. Calif. Publ. Zool. 13(12): 447-494; 1916.

Horst, G. R.; Langworthy, M. L.; Wadsworth, C. L. Micro villi in the renal pelvis and collecting ducts of the pocket gopher *Thomomys bottae*. Anat. Rec. 175(2): 346; 1973.

Howard, W. E. Growth rate of nails on adult pocket gophers. J. Mammal. 34(3): 394-396; 1953.

Howard, W. E.; Smith, M. E. Rate of extrusive growth of pocket gophers. J. Mammal. 33(4): 485-487; 1952.

Ingles, L. G. Pigmental variations in populations of pocket gophers. Evolution. 4: 353-357; 1950.

Johnson, D. R.; Groepper, K. L. Bioenergetics of north plains rodents. Am. Midl. Nat. 84: 537-548; 1970.

Kaup, L. Investigations on the muscular system of the hind extremity in bipedal rodents. Zool. Anz. 194(5-6): 416; 1975.

Kaup, L. Investigations on the bones of the hind extremity and the pelvis in bipedal rodents. Zool. Anz. 196(3-4): 241-254; 1976.

Kay, F. R. Two 3 di phospho glycerate blood oxygen dissociation and the biology of mammals. Comp. Biochem. Physiol. A. Comp. Physiol. 57(3): 309-316; 1977.

Kennerly, T. E., Jr. Comparisons of morphology and life history of two species of pocket gophers. Texas J. Sci. 10(2): 133-146; 1958.

King, B. F.; Tibbitts, F. D. Ultrastructural observations on cytophasmic lamellar inclusions in oocytes of the rodent *Thomomys townsendii*. Anat. Rec. 189(2): 263-272; 1977.

LaVoie, G. K.; Tietjen, H. P.; Fall, M. W. Albinism in *Thomomys talpoides* from Colorado. Great Basin Nat. 31(3): 181; 1971.

Lechner, A. J. Metabolic performance during hypoxia in native and acclimated pocket gophers. J. Appl. Physiol. Respir. Environ. Exercise Physiol. 43(6): 965-970; 1977.

Lechner, A. J. The scaling of maximal oxygen consumption and pulmonary dimensions in small mammals. Respir. Physiol. 34(1): 29-44; 1978.

Lechner, A. J. Electrophoretic characterization of the hemo globins in pocket gophers of the genus *Thomomys*. Comp. Biochem. Physiol. B. Comp. Biochem. 61(1): 73-76; 1978.

Levine, H. P.; Moody, P. A. Serological investigations of rodent relationships. Physiol. Zool. 12(4): 400-411; 1939.

Lidicker, W. Z., Jr. Regulation of numbers in small mammal populations—historical reflections and a synthesis. In: Snyder, D. P., ed. Populations of small mammals under natural selection. Pittsburgh: University of Pittsburgh; 1976: 122-141. (Snyder, D. P., ed. Special Publications Series, Pymatuning Laboratory of Ecology: v. 5).

Matthew, W. D. On the osteology and relationships of *Paramys* and the affinities of the Ischryomyidae. Am. Mus. Nat. Hist. Bull. 28: 43-72; 1910.

McCarley, W. H. Color mutations in a small partially isolated population of pocket gophers (*Ceomys breviceps*). J. Mammal. 32: 338-342; 1951.

McIntosh, W. C. On abnormal teeth in certain mammals, especially in the rabbit. In: Transactions, 1929 Royal Society Edinburgh: Eighth ordinary meeting; 1929 June 3; Edinburgh. Edinburgh: Royal Society of Edinburgh, Transactions. 56: 333-407; 1930.

Miller, M. A. Size characteristics of the Sacramento Valley pocket gopher *Thomomys bottae navus* Merriam. J. Mammal. 33(4): 442-456; 1952.

Miller, R. S. Rate of incisor growth in the mountain pocket gopher. J. Mammal. 39(3): 380-385; 1958.

Moore, T. D.; Spence, L. E.; Dugnolle, C. E. Identification of the dorsal guard hairs of some mammals of Wyoming. Bull. No. 14. Cheyenne, WY: Wyoming Fish and Game Department; 1974. 186 p.

Morejohn, G. V.; Howard, W. E. Molt in the pocket gopher, *Thomomys bottae*. J. Mammal. 37(2): 201-213; 1956.

Mossman, H. W.; Hisaw, F. L. The fetal membranes of the pocket gopher, illustrating an intermediate type of rodent membrane formation. Am. J. Anat. 66(3): 376-391; 1940.

Nevo, E. Adaptive convergence and divergence of subterranean mammals. In: Johnson, R. F.; Frank, P. W.; Michner, C. D., eds. Annual review of ecology and systematics, Vol. 10. Palo Alto, CA: Annual Reviews; 1979: 269-308. ISBN: 0-8243-1410-7.

Nielson, P. E. The fetal membranes of the kangaroo rat, *Dipodomys*, with a consideration of the phylogeny of the Geomyidae. Anat. Rec. 77(1): 103-127; 1940.

Orcutt, E. E. Studies on the muscles of the head, neck and pectoral appendages of *Geomys bursarius*. J. Mammal. 21(1): 37-52; 1940.

University of Pittsburgh. Radioecology of small vertebrate species under natural environments. Pittsburgh, PA: University of Pittsburgh; Progress Report 1960-1971. 83 p.

University of Pittsburgh. Radioecology of small vertebrate species under natural environments. Pittsburgh, PA: University of Pittsburgh; Progress Report, December 1, 1969-November 30, 1970. 47 p.

Ross, J. P. Seasonal variation of thermo regulation in the Florida pocket gopher *Geomys pinetis*. Comp. Biochem. Physiol. A. Comp. Physiol. 66(1): 119-126; 1980.

Rudd, R. L.; Mullen, D. A. Adrenal gland responses to experimental manipulations of captive pocket gophers (*Thomomys umbrinus*). J. Mammal. 44: 451-446; 1963.

Schimpf, D. J.; Henderson, J. A.; MacMahon, J. A. Some aspects of succession in the spruce-fir forest zone of northern Utah. Great Basin Nat. 40: 1-26; 1980.

Smith, C. F. Weights of pocket gophers. J. Mammal. 21: 220; 1940.

Storer, T. I.; Gregory, P. W. Color aberrations in the pocket gopher and their probable genetic explanation. J. Mammal. 15(4): 300-312; 1934.

Thomson, S. C. Studies of the anatomy of the extrahepatic biliary tract in Mammalia. Publ. No. 481, Zool. Series Vol. 22, No. 6. Chicago, IL: Field Museum of Natural History; 1940: 415-430.

Tryon, C. A.; Kondric, W. R.; Cunningham, H. N. Measurement of relative thyroid activity in free ranging rodents along an altitudinal transect. Nature. 218: 278-280; 1968.

Vaughan, T. A. Cranial asymmetry in the pocket gopher. J. Mammal. 42(3): 412-413; 1961.

Vaughan, T. A.; Hansen, R. M. Activity rhythm of the plains pocket gopher. J. Mammal. 42(4): 541-543; 1961.

Wade, O.; Gilbert, P. T. The abnormal growth of the molar teeth and the front claws of an adult pocket gopher, *Geomys bursarius* (Shaw). Am. Midl. Nat. 16(6): 960-961; 1935.

Webber, P. J.; May, D. E. The magnitude and distribution of below ground plant structures in the alpine tundra of Nivot Ridge, Colo. Arctic and Alpine Res. 9: 157-174; 1977.

Wahlert, J. H. Cranial foramina and relationships of the Eomyoidea Rodentia: geomorpha skill and upper teeth of *Kansasimys*. Am. Mus. Navitates No. 2645. New York: American Museum of National History; 1978. 16 p.

Woods, C. A. The hyoid laryngeal and pharyngeal regions of *Bathyergid* and other selected rodents. J. Morphol. 147(2): 229-250; 1975.

Yunker, V. M.; Alekseeva, G. V. Characteristics of hemopoiesis in hibernating gophers *Citellus erythrogenus*. J. Evol. Biochem. Physiol. 10(2): 171-173; 1974.

Reproduction, Growth, and Aging (RGA)

Aldous, S. E. Some breeding notes on rodents. J. Mammal. 16(2): 129-131; 1935.

Andersen, D. C. Observations on reproduction, growth, and behavior of the northern pocket gopher (*Thomomys talpoides*). J. Mammal. 59: 418-422; 1978.

Andersen, D. C. Population dynamics and bioenergetics of a fossorial rodent, the northern pocket gopher (*Thomomys talpoides*) in a spruce-fir ecosystem. Logan, UT: Utah State University; 1980. 147 p. Dissertation.

Andersen, D. C.; MacMahon, J. A. Population dynamics and bioenergetics of a fossorial herbivore, *Thomomys talpoides* (Rodentia:Geomyidae), in a spruce-fir sere. Ecol. Monogr. 51(2): 179-202; 1981.

Anthony, A. W. Notes on the young of the southern pocket gopher. J. Mammal. 4(2): 126-127; 1923.

Barrington, B. A., Jr. Description of birth and young of the pocket gopher *Geomys floridanus*. J. Mammal. 23(4): 428-430; 1942.

Bond, R. M. The breeding habits of *Thomomys bottae* in Orange County, Calif. J. Mammal. 27(2): 172-174; 1946.

Brown, L. N. Breeding biology of pocket gopher (*Geomys pinetis*) in southern Florida. Am. Midl. Nat. 85: 45-53; 1971.

Burt, W. H. On the breeding habits of pocket gophers. Murrelet. 14(2): 42; 1933.

Desy, E. A.; Druecker, J. D. The estrous cycle of the plains pocket gopher *Geomys bursarius* in the laboratory. J. Mammal. 60(1): 235-236; 1979.

Dixon, J. The breeding season of the pocket gopher in California. J. Mammal. 10(4): 327-328; 1929.

Ewel, K. C. Annual reproductive cycle of the male pocket gopher (*Geomys pinetis*). Gainesville, FL: University of Florida; 1970. 78 p. Dissertation.

Gunther, W. C. Studies on the male reproductive system of the California pocket gopher (*Thomomys bottae nauvus* Merriam). Am. Midl. Nat. 55(1): 1-40; 1956.

Gunther, W. C. Some dietary effects on the estrous cycle of the female California pocket gopher, *Thomomys bottae nauvus* (Merriam). In: Proceedings, 1956 Indiana Academy of Science; Fall Meeting; 1956 October 11-13; Bloomington, IN. Indianapolis, IN: Indiana Academy of Science, 1957: 331-336.

Hansen, R. M. Age and reproductive characteristics of mountain pocket gophers in Colorado. J. Mammal. 41(3): 323-335; 1960.

Hipply, D. J. An evaluation of the effect of mestranol on the reproductive systems of valley pocket gophers (*Thomomys bottae*) in central Arizona. Tucson, AZ: University of Arizona; 1969. 42 p. Thesis.

Horn, E. E. Some notes concerning the breeding habits of *Thomomys townsendi* observed near Vale, Malheur County, Oregon, during the spring 1921. J. Mammal. 4(1): 37-39; 1923.

Ingles, L. G. Field observations on the growth of young mountain pocket gophers. Murrelet. 30(2): 35-36; 1949.

Kennedy, J.; Brown, R.; Brown, C.; Bowman, K. The annual reproductive cycle of the plains pocket gopher *Geomys bursarius* in the panhandle of Nebraska, USA. In: Proceedings, 1976 Nebraska Academy of Sciences and Affiliated Societies: Abstracts of papers presented at the 86th Annual Meeting; 1976 April 23-24; Lincoln, NB. Lincoln, NB: Nebraska Academy of Sciences and Affiliated Societies; 1976: 64.

Lay, D. M. Observations on reproduction in a population of pocket gophers *Thomomys bottae* from Nevada. Southwest Nat. 23(3): 375-380; 1978.

Lee, T. G. A comparison between the implantation stages in *Dipodomys* and *Geomys*. Science. 27(702): 918; 1908.

Livezey, B. C.; Verts, B. J. Estimates of age and age structure in Mazama pocket gophers *Thomomys mazama*. Murrelet. 60(2): 38-41; 1979.

McCafferty, D.; Houfek, S. The effect of alpha chlorohydrin on the male reproductive system of *Geomys bursarius*. In: Proceedings, 1976 Nebraska Academy of Sciences and Affiliated Societies: Abstracts of papers presented at the 86th Annual Meeting; 1976 April 23-24; Lincoln, NB. Lincoln, NB: Nebraska Academy of Sciences and Affiliated Societies; 1976: 65.

Miller, M. A. Reproductive rates and cycles in the pocket gopher. J. Mammal. 27(4): 335-358; 1946.

Mossman, H. W. The thecal gland and its relation to the reproductive cycle: a study of the cyclic changes in the ovary of the pocket gopher *Geomys bursarius* (Shaw). Am. J. Anat. 61: 289-319; 1937.

Reid, V. H. Population biology of the northern pocket gopher. In: Turner, G. T. (and others), eds. Pocket gophers and Colorado mountain rangeland. Bull. 554S. Fort Collins, CO: Colorado State University, Agriculture Experiment Station; 1973. 90 p.

Reid, V. H. Population dynamics of northern pocket gophers on rangelands in western Colorado. Fort Collins, CO: U.S. Bureau of Sport Fisheries and Wildlife; 1981. 36 p. (Draft—to be published.)

Scheffer, T. H. Breeding habits of the mole and the gopher. Murrelet. 5(1): 3-4; 1924.

Scheffer, T. H. Breeding records of Pacific Coast pocket gophers. J. Mammal. 19(2): 220-224; 1938.

Schramm, P. Copulation and gestation in the pocket gopher. J. Mammal. 42(2): 167-170; 1961.

Smolen, M. J.; Genoways, H. H.; Baker, R. J. Demographic and reproductive parameters of the yellow-cheeked pocket gopher *Pappogeomys castonops*. J. Mammal. 61(2): 224-236; 1980.

Vaughan, T. A. Reproduction in the plains pocket gopher in Colorado. J. Mammal. 43(1): 1-13; 1962.

Vaughan, T. A. Reproduction and population densities in a montane small mammal fauna. In: Jones, J. K., Jr., ed. Contributions in mammalogy. Misc. Publ. 51. Lawrence, KS: University of Kansas, Museum of Natural History; 1969: 51-74.

Wight, H. M. Breeding habits and economic relations of The Dalles pocket gopher. J. Mammal. 11: 40-48; 1930.

Wing, E. S. Reproduction in the pocket gopher in north central Florida. J. Mammal. 41(1): 35-43; 1960.

Wirtz, J. H. Reproduction in the pocket gopher *Thomomys talpoides rostralis* Hall and Montague. J. Colo.-Wyo. Acad. Sci. 4(6): 62; 1954.

Wood, J. E. Reproductive pattern of the pocket gopher (*Geomys breviceps*). J. Mammal. 30: 36-44; 1949.

Parasites and Disease (PD)

Allred, D. M. Plague-important fleas and mammals in Utah and the western U.S. Great Basin Nat. 12(1-4): 67-75; 1951.

Cartwright, O. L. Concerning *Aphodius aegrotus* and *Aphodius geomysi*. Coleopt. Bull. 32(3): 258; 1978.

Chamberlain, R. W. Four new species of Collembola. Great Basin Nat. 4: 39-48; 1943.

Coffman, C. C.; McDaniel, B. The description of *Geomylichus geomydis* new species and rates of infestations on 1 of its host *Geomys bursarius bursarius* in South Dakota, USA. Acarologia. 17(1): 183-194; 1975.

Ewing, H. E. The taxonomy of the mallophagan family Trichodectidae with special reference to the New World fauna. J. Parasitol. 22(3): 233-246; 1936.

Gordon, R. D. Studies on the genus *Aphodius* of the USA and Canada Coleoptera Scarabaeidae: Part 2, A new species from Georgia USA. Entomological Society of Washington, Proceedings 76(4): 455-459; 1974.

Hellenthal, R. A.; Price, R. D. Louse host associations of *Geomydoecus* Mallophaga: Trichodectidae with the yellow-faced pocket gopher *Pappogeomys castanops* Rodentia: Geomyidae. J. Med. Entomol. 13(3): 331-336; 1976.

Hopkins, G. H. E. The host-associations of the lice of mammals. Zoological Society of London, Proceedings 119: 387-604; 1949.

Hopkins, G. H. E.; Clay, T. A check list of the genera and species of Mallophaga. London: British Museum; 1952. 362 p.

Hubbard, C. A. Our western giant pocket gopher fleas. Pac. Univ. Bull. 4C: 1-8; 1943.

Hubbard, C. A. Fleas of western United States; their relation to the public health. Ames, IA: Iowa State College Press; 1947. 533 p.

Jellison, W. L. *Cuterebra thomomuris* sp. Nov., a warble from the pocket gopher, *Thomomys talpoides*. (Rodentia:Geomyidae). J. Parasitol. 35(5): 482-486; 1949.

Keegan, H. L. Six new mites of the superfamily Parasitoidea. American Microscopical Society, Transactions 65(1): 69-77; 1946.

Karitonova, N. N.; Leonov, Y. A. On the role of the red-cheeked suslik in the Omsk haemorrhagic fever (OHF) focus in northern Kulunda. Cairo, Egypt: Naval Medical Research Unit No. 3, Department of Medical Zoology; 1969. 3 p.

Mahunka, S. New data to the knowledge of *Pygmephorus* species, *Acari tarsonemida*, living on small mammals in America. Parasitol. Hung. 7: 197-200; 1974.

Mahunka, S. 3 new scutacarid species *Acari tarsonemida* from the nests of small mammals in the USA. Parasitol. Hung. 10: 129-134; 1977.

McCoy, G. W. The susceptibility of gophers, field mice and ground squirrels to plague infection. J. Infect. Dis. 6: 28; 1909.

McCoy, G. W. The susceptibility to plague of the weasel, the chipmunk and the pocket gopher. J. Infect. Dis. 8: 42-46; 1911.

Miller, R. S.; Ward, R. A. Ectoparasites of pocket gophers from Colorado. Am. Midl. Nat. 64(2): 382-391; 1960.

O'Farrell, T. P. Small mammals: their parasites and pathologic lesions, on the arid lands ecology reserve Benton County, Washington, USA. Am. Midl. Nat. 93(2): 377-387; 1975.

Price, R. D. Host records for *Gemydoecus* (Mallophaga:Trichodectidae) from the *Thomomys bottae umbrinus* complex (Rodentia:Geomyidae). J. Med. Entomol. 9: 537-544; 1972.

Price, R. D. Two new species of *Geomydoecus* from Costa Rican pocket gophers Mallophaga:Trichodectidae. Entomological Society of Washington, Proceeding 76(1): 41-44; 1974.

Price, R. D. The *Geomydoecus expansus* Mallophaga:Trichodectidae from the southeastern USA pocket gophers Rodentia:Geomyidae. Entomological Society of Washington, Proceedings 77(1): 61-65; 1975.

Price, R. D.; Hellenthal, R. A. A reconstruction of *Geomydoecus expansus*, Mallophaga:Trichodectidae from the yellow-faced pocket gopher Rodentia:Geomyidae. J. Kans. Entomol. Soc. 48(1): 33-42; 1975.

Price, R. D.; Hellenthal, R. A. A review of the *Geomydoecus taxanus* complex Mallophaga:Trichodectidae from *Geomys* and *Pappogeomys*:Rodentia:Geomyidae J. Med. Entomol. 12(4): 401-408; 1975.

Price, R. D.; Hellenthal, R. A. The *Geomydoecus* Mallophaga:Trichodectidae from the Hispid pocket gopher Rodentia:Geomyidae. J. Med. Entomol. 12(6): 695-700; 1976.

Price, R. D.; Hellenthal, R. A. A review of the *Geomydoecus tolucae* complex Mallophaga:Trichodectidae from *Thomomys* Rodentia:Geomyidae based on qualitative and quantitative characters. J. Med. Entomol. 16(4): 265-274; 1979.

Price, R. D.; Hellenthal, R. A. The *Geomydoecus neocopei* complex Mallophaga:Trichodectidae of the *Thomomys umbrinus* pocket gophers Rodentia:Geomyidae of Mexico. J. Kans. Entomol. Soc. 53(3): 567-580; 1980.

Price, R. D.; Hellenthal, R. A. The *Geomydoecus oregonus* complex Mallophaga:Trichodectidae of the western USA pocket gophers Rodentia:Geomyidea. Entomological Society of Washington, Proceedings 82(1): 25-38; 1980.

Price, R. D.; Timm, R. M. Description of male of *Geomydoecus scleritus* R. Mallophaga:Trichodectidae from the southeastern pocket gopher. J. Ga. Entomol. Soc. 14(2): 162-165; 1979.

Richens, V. B. Larvae of botfly in the northern pocket gopher. J. Mammal. 46(4): 689-690; 1965.

Rust, R. W. The acarinium of pocket gopher, *Thomomys bottae* (Rodentia:Geomyidae). J. Med. Entomol. 10: 169-175; 1973.

Rust, R. W. The population dynamics and host utilization of *Geomydoecus oregonus* a parasite of *Thomomys bottae*. Oecologia. 15(3): 287-304; 1974.

Skidmore, L. V. Note on a new species of Coccidia from the pocket gopher (*Geomys bursarius*) Shaw. J. Parasitol. 15(3): 183-184; 1929.

Smiley, R. L.; Whitaker, J. O., Jr. Mites of the genus *Pygmephorus acari* Pygnephoridae on small mammals in North America. Acta Zool. Acad. Sci. Hung. 25(3-4): 383-408; 1979.

Szabo, I. The past and the future tasks of Hungarian Siphonaptera research. Allattani Kozl. 63(1-4): 147-153; 1976.

Timm, R. M.; Price, R. D. The taxonomy of *Geomydoecus*:Mallophaga: Trichodectidae from the *Geomys bursarius* complex Rodentia:Geomyidae. J. Med. Entomol. 17(2): 126-145; 1980.

Timm, R. M.; Price, R. D. A new species *Geomydoecus dalgleishi* new species Mallophaga:Trichodectidae from the Texas pocket gopher *Geomys personatus* Rodentia:Geomyidae. J. Kansas. Entomol. Soc 52(2): 264-268; 1979.

Todd, K. S.; Lepp, D. L. Endoparasites of the northern pocket gopher from Wyoming. J. Wildl. Dis. 7(2): 100-104; 1971.

Tuszynski, R. C.; Whitaker, J. O. External parasites of pocket gophers, *Geomys bursarius* from Indiana. Am. Midl. Nat. 87(2): 545-548; 1972.

Ubelaker, J. E.; Downhower, J. F. Parasites recovered from *Geomys bursarius* in Douglas Co., Kansas. Kansas Academy of Science, Transactions 68(1): 206-208; 1965.

Ward, R. A. Host-parasite relations of the Mallophaga (biting lice) of pocket gophers. Entomol. Soc. Am. Bull. 3(3): 22; 1957.

Whitaker, J. O., Jr.; Goff, R. J. Mallophaga of wild mammals of Indiana, USA. Entomol. News. 90(1): 23-25; 1979.

Wilson, N.; Oliver, G. V., Jr. New records of chewing lice Mallophaga:Boopidae and Trichodectidae from native mammals in Texas, USA. Southwest Entomol. 4(2): 156-162; 1979.

Behavior (B)

Arkley, R. J. The mima mounds. Sci. Mon. 66(2): 175-176; 1948.

Arkley, R. J.; Brown, H. C. The origin of mima mound (hog wallow) microrelief in the far western states. Soil Sci. Soc. Am., Proc. 18: 195-199; 1954.

Axthelm, D.; Lee, D. Burrowing habits of the plains pocket gopher, *Geomys bursarius*. In: Proceedings, 1976 Nebraska Academy of Sciences and Affiliated Societies: Abstracts of papers presented at the 86th Annual Meeting; 1976 April 23-24; Lincoln, NB. Lincoln, NB: Nebraska Academy of Sciences and Affiliated Societies; 1976: 63.

Baker, A. E. M. Interspecific aggressive behavior of pocket gophers *Thomomys bottae* and *T. talpoides* (Geomyidae:Rodentia). Ecology. 55(3): 671-673; 1974.

Breckenridge, W. J. Actions of the pocket gopher (*Geomys bursarius*). J. Mammal. 10: 336-339; 1929.

Bryant, H. C. Nocturnal wanderings of the California pocket gopher. Univ. Calif. Publ. Zool. 12(2): 25-29; 1913.

Chapman, R. C.; Bennett, A. F. Physiological correlates of burrowing in rodents. Comp. Biochem. Physiol. A. Comp. Physiol. 51(3): 599-604; 1975.

Dalquest, W. W.; Scheffer, V. B. The origin of the mima mounds of western Washington. J. Geol. 50:68-84; 1942.

Dice, L. R. *Thomomys* the engineer - friend or foe? Am. For. 45(10): 512; 1939.

English, P. F. Some habits of the pocket gopher, *Geomys breviceps breviceps*. J. Mammal. 13: 126-132; 1932.

Gabrielson, I. N. *Thomomys* the engineer. Am. For. 44(10): 453-454, 478-479; 1938.

Hansen, R. M. Pocket gopher digging behavior in rocky soils. Progress Report 232. Fort Collins, CO: Colorado State University, Agriculture Experiment Station; 1967. 2 p.

Hansen, R. M.; Miller, R. S. Observations on the plural occupancy of pocket gopher burrow systems. J. Mammal. 40(4): 577-584; 1959.

Hansen, R. M.; Morris, M. J. Movement of rocks by northern pocket gophers. J. Mammal. 49(3): 391-399; 1968.

Hickman, G. C.; Brown, L. N. Mound building behavior of the southeastern pocket gopher (*Geomys pinetis*). J. Mammal. 54(3): 786-790; 1973.

Hickman, G. C. The maternal behavior of a Mexican pocket gopher *Pappogeomys castanops*. Southwest Nat. 20(1): 142-144; 1975.

Hickman, G. C. Swimming behavior in representative species of the 3 genera of North American *Geomyid*. Southwest Nat. 21(4): 531-538; 1977.

Kanavau, J. L.; Havenhill, R. M. Compulsory regime and control of environment in animal behavior. Part 3. Light level preferences of small nocturnal mammals. Behavior. 59(304): 203-225; 1976.

Katz, S. J. Tool using behavior of the pocket gopher *Thomomys bottae*. Southwest Nat. 25(2): 270-271; 1980.

Kelly, A. O. The mima mounds. Sci. Mon. 66(2): 174-175; 1948.

Laycock, W. A. Seasonal periods of surface inactivity of the pocket gopher. J. Mammal. 38(1): 132-133; 1957.

Marshall, W. H. *Thomomys* as burrowers in the snow. J. Mammal. 22(2): 196-197; 1941.

Miller, M. A. Seasonal trends in burrowing of pocket gophers. J. Mammal. 29: 38-44; 1948.

Miller, R. S.; Bond, H. E. The summer burrowing activity of pocket gophers. J. Mammal. 41(4): 469-475; 1960.

Mohr, C. O.; Mohr, W. P. Abundance and digging rate of pocket gophers, *Geomys bursarius*. Ecology. 17(2): 325-327; 1936.

Parvin, J. B. On the habits of the gopher of Illinois (*Geomys bursarius*). 9th Annual Report. Washington, DC: Smithsonian Institution; 1854: 293-294.

Price, W. A. Pocket gophers as architects of mima (pimple) mounds of the western U.S. Texas J. Sci. 1: 1-17; 1949.

Richens, V. A. Notes on the digging activity of the northern pocket gopher. J. Mammal. 47(3): 531-533; 1966.

Scheffer, T. H. Habits and economic status of the pocket gophers. Tech. Bull. 224. Washington, DC: U.S. Department of Agriculture; 1931. 27 p.

Scheffer, T. H. Mound construction of the pocket gopher. Murrelet. 29: 9-10; 1948.

Scheffer, V. B. The mystery of the mima mounds. Sci. Mon. 65: 283-294; 1947.

Scheffer, V. B. Son exclusios del oeste de Norteamerica los micromoniticulos de tipo mima? Invest. Zool. Chil. 2(6): 89-94; 1954.

Scheffer, V. B. Do fossorial rodents originate mima type microrelief? Am. Midl. Nat. 59(2): 505-510; 1958.

Scheffer, V. B.; Kruckeberg, A. The mima mounds. BioScience. 16(11): 800-801; 1966.

Sharp, W. M. A pocket gopher (*Geomys lutescens*) travels backward. J. Mammal. 24(1): 99; 1943.

Stallings, J. H. The mima mounds. Sci. Mon. 66: 269-270; 1948.

Vaughan, T. A. Food handling and grooming behaviors in the plains pocket gopher. J. Mammal. 47(1): 132-133; 1966.

Vaughan, T. A. Resource allocation in some sympatric subalpine rodents. J. Mammal. 55(4): 764-795; 1974.

Vaughan, T. A.; Hansen, R. M. Experiments on interspecific competition between two species of pocket gophers. Am. Midl. Nat. 72(2): 444-452; 1964.

Virchow, D. Use of telemetry in the study of pocket gopher *Geomys bursarius* movements and activity patterns. In: Proceedings, 1977 Nebraska Academy of Sciences and Affiliated Societies: 87th annual meeting abstracts; 1977 April 15-16; Lincoln, NB. Lincoln, NB: Nebraska Academy of Sciences and Affiliated Societies; 1977: 23.

Vleck, D. The energy cost of burrowing by the pocket gopher *Thomomys bottae*. Physiol. Zool. 52(2): 122-136; 1979.

Watts, D. E. Burrowing habits of the plains pocket gopher in northcentral and northeastern Oklahoma during the fall and winter of 1969-1970. Stillwater: Oklahoma State University; 1970. 72 p. Dissertation.

Food and Feeding Habits (FF)

Aldous, C. M. Pocket gopher food caches in central Utah. J. Wild. Manage. 9(4): 327-328; 1945.

Aldous, C. M. The feeding habits of the pocket gopher *Thomomys talpoides moorei*, on the high mountain ranges of central Utah. J. Mammal. 32: 84-87; 1951.

Bleak, A. T. Disappearance of plant material under a winter snow cover. Ecology. 51(5): 915-917; 1970.

Burton, D. H.; Black, H. C. Feeding habits of Mazama pocket gopher in eastern Colorado. J. Mammal. 45(4): 588-597; 1978.

Cummins, E. B. Pocket gopher feeding preferences for ponderosa pine strains. Moscow, ID: University of Idaho; 1975. 51 p. Thesis.

Cunningham, H. N., Jr. An ecological study of the northern pocket gopher, *Thomomys talpoides* (Richardson) in relation to available food resources along an altitudinal transect. Pittsburgh, PA: University of Pittsburgh; 1966. 218 p. Dissertation.

Gunther, W. C. Some dietary effects on the estrous cycle of the female California pocket gopher *Thomomys bottae navus* (Merriam). In: Proceedings, 1956 Indiana Academy of Science: Fall meeting; 1956 October 11-13; Bloomington, IN. Indianapolis, IN: Indiana Academy of Science; 66: 331-336; 1957.

Howard, W. E. Relation between low temperature and available food to survival of small rodents. J. Mammal. 32(3): 300-312; 1951.

Hungerford, K. E. Food preferences and food location by pocket gophers in Idaho. In: Proceedings, 7th vertebrate pest conference; 1976 March 9-11; Monterey, CA. Sacramento, CA: Department of Food and Agriculture, Control and Erradication, Vertebrate Pest Conference 1976: 131-138.

Luce, D. G.; Case, R. M. Plains pocket gopher food habits in alfalfa fields. In: Proceedings, 1977 Nebraska Academy of Sciences and Affiliated Societies: 87th annual meeting abstracts; 1977 April 15-16; Lincoln, NB. Lincoln, NB: Nebraska Academy of Sciences and Affiliated Societies; 1977: 17.

Luce, D. G.; Case, R. M.; Stubbendieck, J. L. Plains pocket gopher food habits in western Nebraska USA rangeland. In: Proceedings, 1978 Nebraska Academy of Sciences and Affiliated Societies; 88th annual meeting abstracts; 1978 April 14-15; Lincoln, NB. Lincoln, NB: Nebraska Academy of Science and Affiliated Societies; 1978: 18-19.

Luce, D. G.; Case, R. M.; Stubbendieck, J. L. Food habits of the plains pocket gopher on western Nebraska Rangeland (impact on forage production). J. Range Manage. 33(2): 129-131; 1980.

Martin, A. C.; Zim, H. S.; Nelson, A. L. American wildlife and plants, a guide to wildlife food habits. New York: Dover Publishing; 1951. 500 p.

Myers, G. T. Food habits of the plains pocket gopher in the sandhills of eastern Colorado. Fort Collins, CO: Colorado State University; 1962. Thesis.

Myers, G. T.; Vaughan, T. A. Food habits of the plains pocket gopher in eastern Colorado. J. Mammal. 45(4): 588-597; 1964.

Radwan, M. A.; Crouch, G. L.; Harrington, C. A. Terpenes of ponderosa pine and feeding preferences by pocket gophers. J. Chem. Ecol. 8(1): 241-253; 1982.

Radwan, M. A.; Ellis, W. D.; Crouch, G. L. Chemical composition and deer browsing of red alder foliage. Res. Pap. PNW-246. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1978. 6 p.

Vaughan, T. A. Food handling and grooming behaviors in the plains pocket gopher. J. Mammal. 47(1): 132-133; 1966.

Vaughan, T. A. Food habits of the northern pocket gophers on shortgrass prairie. Am. Midl. Nat. 77(1): 176-189; 1967.

Wade, O. Food habits of a pocket gopher (*Geomys lutescens*). J. Mammal. 8(4): 310-311; 1927.

Ward, A. L. Mountain pocket gopher food habits in Colorado. J. Wildl. Manage. 24(1): 89-92; 1960.

Ward, A. L. Food habits and competition. In: Turner, G. T. (and others), eds. Pocket gophers and Colorado mountain rangeland. Bull. 554S. Fort Collins, CO: Colorado State University, Agriculture Experiment Station; 1973: 43-49.

Ward, A. L.; Keith, J. O. Feeding habits of pocket gophers on mountain grasslands, Black Mesa, Colorado. Ecology. 43(4): 744-749; 1962.

Wilks, B. J. 1962. Reingestion in geomyid rodents. J. Mammal. 43(2): 267; 1962.

Yorgason, I. J. 1960. An ecological study of the food habits of the pocket gopher *Thomomys talpoides rostralis*. Laramie, WY: University of Wyoming; 1960.

Genetics (G)

Avise, J. C.; Giblin-Davidson, C.; Laerm, J.; Patton, J. C.; Lansman, R. A. Mitochondrial DNA clones and matriarchal phylogeny within and among geographic populations of the pocket gopher *Geomys pinetis*. National Academy of Sciences USA, Proceedings 76(12): 6694-6698; 1979.

Baker, R. J.; Williams, S. L.; Patton, J. C. Chromosomal variation in the plains pocket gopher *Geomys bursarius major*. J. Mammal. 54(3): 765-769; 1973.

Berry, D. L.; Baker, R. J. Chromosomes of pocket gophers of the genus *Pappogeomys* subgenus *Cratogeomys*. J. Mammal. 53(2): 303-309; 1972.

Cross, J. C. Comparative study of the chromosomes of rodents. J. Morphol. Physiol. 52(2): 373-401; 1931.

Dowler, R. C.; Genoways, H. H. Variation in *Pappogeomys castanops* Geomyidae on the Llano Estacade of Texas and New Mexico. Southwest Nat. 24(4): 577-602; 1979.

Fry, K.; Salser, W. Nucleotide sequences of heavy strand alphs satellite DNA from kangaroo rat *Dipodomys ordii* and characterization of similar sequences in other rodents. Cell. 12(4): 1069-1084; 1977.

George, W. Conservatism in the karyotypes of 2 african molerats Rodentia:Bathyergidae. Z. Saugetierkunde. 44(5): 278-285; 1979.

Hart, E. B.; Patterson, R. R. Chromosomes of the yellow-faced pocket gopher *Pappogeomys castanops* in Kansas. Kansas Academy of Science, Transactions 77(4): 239-243; 1974.

Hinesley, L. L.; Thaeler, C. S., Jr. Karyotype and distribution of the southern pocket gopher *Thomomys umbrinus emotus*. J. Mammal. 58(2): 235-237; 1977.

Judd, S. R. *Thomomys agrestis* a study of speciation and intra populational chromosome variation in southern Colorado. N. Mex. Acad. Sci. Bull. 18(1): 39-40; 1978.

Kennerly, T. E., Jr. Gene flow pattern and swimming ability of the pocket gopher. Southwest. Nat. 8(2): 85-88; 1963.

Laguarda-Figueras, A.; Paulette, J.; Romero-Jarero, J.; Scaglia-de-Paulette, S. Chromosome analysis and meiotic behavior of *Pappogeomys merriami merriami*. Experientia (Basel). 29(7): 889-890; 1973.

Lansman, R. A.; Avise, J. C.; Shade, R. Restriction endo nucleases used to measure mitochondrial DNA sequence diversity in natural populations. J. Supramol. Struct. 9: Supplement 3; 1979. 143 p.

Mazrimas, J. A. Similarity of satellite DNA from 4 rodent families. Fed. Proc. 35(7): 1631; 1976.

Nevo, E. Test of selection and neutrality in natural population. Nature. 244(5418): 573-575; 1973.

Nevo, E.; Kim, Y. J.; Shaw, C. R.; Thaeler, C. S., Jr. Genetic variation, selection and speciation in *Thomomys talpoides* pocket gophers. Evolution. 28(1): 1-23; 1974.

Patton, J. L. An analysis of natural hybridization between the pocket gophers, *Thomomys bottae* and *Thomomys umbrinus*, in Arizona. J. Mammal. 54(3): 561-584; 1973.

Patton, J. L.; Dingman, R. E. Chromosome studies of pocket gophers, genus *Thomomys*. I. The specific status of *Thomomys umbrinus* Richardson in Arizona. J. Mammal. 49(1): 1-13; 1968.

Patton, J. L.; Yang, S. Y. Genetic variation in *Thomomys bottae* pocket gophers: macrogeographic patterns. Evolution. 31(4): 697-720; 1977.

Patton, J. L.; Feder, J. H. Genetic divergence between populations of the pocket gopher *Thomomys umbrinus*. Z. Saeugetierko 43(1): 17-30; 1978.

Patton, J. L.; Baker, R. J.; Genoways, H. H. Apparent chromosomal heterosis in a fossorial mammal. Am. Nat. 116(1): 143-146; 1980.

Patton, J. L.; Hafner, J. C.; Hafter, M. S.; Smith, M. F. Hybrid zones in *Thomomys bottae* pocket gophers genetic, phenetic and ecologic concordance patterns. Evolution. 33(3): 860-876; 1979.

Penney, D. F.; Zimmerman, E. G. Genic divergence and local population differentiation by random drift in the pocket gopher genus *Geomys*. Evolution. 30(30): 473-483; 1976.

Pierce, B. A.; Mitton, J. B. A relationship of genetic variation within and among populations: an extension of the Kluge kerfoot phenomenon. Syst. Zool. 28(1): 63-70; 1979.

Sarich, V. M. The utility of electrophoretic data in evaluating close phyletic relationships cercopithecoidea. Am. J. Phys. Anthropol. 49(1): 150; 1974.

Sarich, V. M. Rates sample sizes and the neutrality hypothesis for electrophoeresis in evolutionary studies. Nature (London) 265(5589): 24-28; 1977.

Sarich, V. M. Electrophoretic systematics at lower taxon levels. Am. J. Phys. Anthropol. 47(1): 158; 1977.

Selander, R. K.; Kaufman, D. W.; Baker, R. J.; Williams, S. L. Genetic and chromosomal differentiation in pocket gophers of the *Geomys bursarius* group. Evolution. 28: 557-564; 1975.

Thaeler, C. S., Jr. Four contacts between ranges of different chromosome forms of the *Thomomys talpoides* complex Rodentia:Geomyidae. Syst. Zool. 23(3): 343-354; 1974.

Thaeler, C. S., Jr. Chromosome polymorphism in *Thomomys talpoides agrestis* Rodentia:Geomyidae. Southwest Nat. 21(1): 105-116; 1976.

Vorontsov, N.; Sokolovskii, V. Genetics at the 1st International Theriological Congress. Sov. Genet. (Engl. Transl.) Genetika. 11(9): 1212-1215; 1975.

Williams, S. L.; Genoways, H. H. Karyotype of *Geomys pinetis* Mammalia:Geomyidae with a discussion of the chromosomal relationships within the genus. Experientia (Basel.) 31(10): 1141-1143; 1975.

Habitat Relationships—Forest Land (HRF)

Anderson, R. J. Relation of the northern pocket gopher to forest habitats in south central Oregon. Corvallis, OR: Oregon State University; 1976. 46 p. Thesis.

Barnes, V. G., Jr. Response of pocket gopher populations to silvicultural practices in central Oregon. In: Black, H. C., ed. Proceedings, symposium on wildlife and forest management in the Pacific Northwest; 1973 September 11-12; Corvallis, OR. Corvallis, OR: Oregon State University, School of Forestry; 1974: 167-175.

Barrett, J. S. Spacing and understory vegetation affect growth of ponderosa pine saplings. Res. Note PNW-27. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1965. 8 p.

Barrett, J. S. Ponderosa pine saplings respond to control of spacing and understory vegetation. Res. Pap. PNW-106. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1970. 16 p.

Barrett, J. S. Ponderosa pine growth and stand management. In: Precommercial thinning of coastal and intermountain forests on the Pacific Northwest: a short course held 1971 February 3-4; Pullman, WA. Pullman, WA: Washington State University; 1971: 5-9.

Barrett, J. W.; Youngberg, C. T. Effect of tree spacing and understory vegetation on water use in a pumice soil. Soil Sci. Soc. Am. Proc. 29: 472-475; 1965.

Black, H. C.; Hooven, E. H. Response of small mammal communities to habitat changes in western Oregon. In: Proceedings, symposium on wildlife and forest management in the Pacific Northwest; 1973 September 11-12; Corvallis, OR. Corvallis, OR: Oregon State University, School of Forestry; 1974: 177-186.

Buechner, H. K. Interrelationships between the pocket gopher and land use. J. Mammal. 23(3): 346-348; 1942.

Clary, W. P.; Ffolliott, P. F. Differences in herbage-timber relationships between thinned and unthinned ponderosa pine stands. Res. Note RM-74. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station; 1966. 4 p.

Clary, W. P.; Ffolliott, P. F.; Jameson, D. A. Relationships of different forest floor layers to herbage production. Res. Note RM-123. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station; 1968. 3 p.

Crouch, G. L. Atrazine improves survival and growth of ponderosa pine (*Pinus ponderosa*) threatened by vegetative competition and pocket gophers (Oregon). For. Sci. 25(1): 99-111; 1979.

Gordon, D. T. Growth response of eastside pine poles to removal of low vegetation. Res. Note PSW-209. Berkeley, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station; 1962. 3 p.

Griffin, J. R. Oak regeneration in the upper Carmel Valley, California. Ecology. 52(5): 862-868; 1971.

Hermann, R. K.; Thomas, H. A. Observations on the occurrence of pocket gophers in southern Oregon pine plantations. J. For. 61(7): 527-529; 1963.

Jameson, D. A. The relationship of the overstory and herbaceous understory vegetation. J. Range Manage. 20(4): 247-249; 1967.

Layne, J. N. Ecology of small mammals in a flatwoods habitat in north central Florida USA with emphasis on the cotton rat *Sigmodon hispidus*. Am. Mus. Novitates No. 2544. New York: American Museum of Natural History; 1974. 48 p.

Lyon, J. L. Problems of habitat management for deer and elk in the northern forests. Res. Pap. INT-24. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1966. 15 p.

Marston, R. B.; Julander, O. Plant cover reductions by pocket gophers following experimental removal of aspen from a watershed area in Utah. J. For. 59(2): 100-102; 1961.

McConnell, B. R.; Smith, J. G. Understory response three years after thinning pine. J. Range Manage. 18(3): 129-132; 1965.

McConnell, B. R.; Smith, J. G. Response of understory vegetation in eastern Washington. J. Range Manage. 23(3): 208-212; 1970.

Minore, D. Shade benefits Douglas-fir in southwestern Oregon cutover area. Tree Planters' Notes. 22(1): 22-23; 1971.

Pase, C. P. Herbage production and composition under immature ponderosa pine stands in the Black Hills. J. Range Manage. 11(5): 238-243; 1958.

Patton, D. R. Deer and elk use of a ponderosa pine forest in Arizona before and after timber harvest. Res. Note RM-139. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station; 1969. 7 p.

Pearson, G. A. Herbaceous vegetation a factor in natural regeneration of ponderosa pine in the Southwest. Ecol. Monogr. 12: 315-339; 1942.

Reynolds, H. G. Effect of logging on understory vegetation and deer use in ponderosa pine forest of Arizona. Res. Note RM-80. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station; 1962. 7 p.

Reynolds, H. G. Use of natural openings in a ponderosa pine forest of Arizona by deer, elk and cattle. Res. Note RM-78. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station; 1962. 4 p.

Reynolds, H. G. Slash cleanup in a ponderosa pine forest affects use by deer and cattle. Res. Note RM-64. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station; 1966. 3 p.

Reynolds, H. G. Use of openings in spruce-fir forests of Arizona by elk, deer, and cattle. Res. Note RM-66. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station; 1966. 4 p.

Reynolds, H. G. Improvement of deer habitat on southwestern forest lands. J. For. 67(11): 803-805; 1969.

Ronco, F. Lessons from artificial regeneration studies in a cutover beetle-killed spruce stand in western Colorado. Res. Note RM-90. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station; 1967. 8 p.

Ronco, F. Shading and other factors affect survival of planted Engelmann spruce seedlings in central Rocky Mountains. Res. Note RM-163. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station; 1970. 7 p.

Stein, W. I. Natural reproduction of Shasta red fir from a single good cone crop. Res. Note PNW-100. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1954. 5 p.

Stein, W. I. A successful direct seeding of sugar pine. Res. Note PNW-25. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1957. 19 p.

Volland, L. A. Relation of pocket gophers to plant communities in the pine region of central Oregon. In: Black, H. C., ed. Forest management in the Pacific Northwest. Corvallis, OR: Oregon State University; 1973: 149-166.

Wakeley, P. C. Planting the southern pines. Agric. Monogr. 18. Washington, DC: U.S. Department of Agriculture, Forest Service; 1954. 233 p.

Youmans, C. C. Characteristics of pocket gopher populations in relation to selected environmental factors in Pelican Valley, Yellowstone National Park. Bozeman: Montana State University; 1979. 79 p. Thesis.

Habitat Relationships—Rangeland and Agricultural Lands (HRR)

Alsager, D. E. Impact of pocket gophers (*Thomomys talpoides*) on the quantitative productivity of rangeland vegetation in southern Alberta: a damage assessment tool. In: Jackson, W. B.; March, R. E., eds. Test methods for vertebrate pest control and management materials: a symposium on test methods for vertebrate pest control and management materials; 1976 March 8; Monterey, CA. Philadelphia, PA: American Society for Testing and Materials; 1977: 47-57. ASTM STP 625.

Basile, J. V. Artificial revegetation studies on depleted big game winter ranges in Idaho: bitterbrush revegetation. Boise, ID: Idaho Fish and Game Department; 1956. 9 p.

Bond, R. M. Range rodents and plant succession. In: Transactions, 1945 North American Wildlife Conference (no meeting). Washington, DC: American Wildlife Institute; 1945: 229-234.

Branson, F. A.; Payne, G. F. Effects of sheep and gophers on meadows of the Bridger Mountains of Montana. J. Range Manage. 11(4): 165-169; 1958.

Buechner, H. K. Interrelationships between the pocket gopher and land use. J. Mammal. 23(3): 346-348; 1942.

Colorado Agriculture Experiment Station. Some relations of pocket gophers to rangelands on Grand Mesa, Colorado. Tech. Bull. 88. Fort Collins, CO: Colorado Agriculture Experiment Station; 1966. 20 p.

Cook, J. B. Pocket gophers spread Canada thistle. Calif. Dep. Agric. Bull. 28: 142-143; 1939.

Cummings, M. W. Grand Mesa pocket gopher study: a five year summary and progress report for 1946. Denver, CO: U.S. Department of the Interior, Bureau of Sport Fisheries and Wildlife, Denver Wildlife Research Center; 1946. Unpublished thesis.

Dearment, R. Habitat improvement evaluation: determination of plant survival in habitat plots. Oklahoma City, OK: Oklahoma Department of Wildlife Conservation; 1951. 15 p.

Dearment, R. Habitat improvement evaluation: determination of utilization of completed plots by bobwhite quail and other wildlife. Oklahoma City, OK: Oklahoma Department of Wildlife and Conservation; 1951. 12 p.

Dixon, J. Rodents and reclamation in the Imperial Valley. J. Mammal. 3(3): 136-146; 1922.

Ellison, L. Establishment of vegetation on depleted subalpine range as influenced by microenvironment. Ecol. Monogr. 19(2): 95-121; 1949.

Ellison, L. Subalpine vegetation of the Wasatch Plateau, Utah. Ecol. Monogr. 24(2): 89-184; 1954.

Ellison, L.; Aldous, C. M. Influence of pocket gophers on vegetation of subalpine grassland in central Utah. Ecology. 33(2): 177-186; 1952.

Fitch, H. S.; Bentley, J. R. Use of California annual-plant forage by range rodents. Ecology. 30: 306-321; 1949.

Garrison, G. A.; Moore, A. W. Relation of the Dallas pocket gopher to establishment and maintenance of range grass plantings. J. Range Manage. 9(4): 181-184; 1956.

Grant, W. E.; French, N. R.; Folse, L. J., Jr. Effects of pocket gopher *Thomomys talpoides* mounds on plant production in short grass prairie ecosystems. Southwest Nat. 25(2): 215-224; 1980.

Hansen, R. M.; Beck, R. F. Habitat of pocket gophers in Cochetopa Creek drainage, Colorado. Am. Midl. Nat. 79(1): 103-117; 1968.

Hansen, R. M.; Reid, V. H. Distribution and adaptations of pocket gophers. In: Turner, G. T. (and others), eds. Pocket gophers and Colorado mountain rangeland. Bull. 554S. Fort Collins, CO: Colorado State University, Agriculture Experiment Station; 1973: 1-19.

Hansen, R. M.; Ward, A. L. Some relations of pocket gophers to rangelands on Grand Mesa, Colorado. Tech. Bull. No. 88. Fort Collins, CO: Colorado State University, Agriculture Experiment Station; 1966. 22 p.

Horn, E. E.; Fitch, H. S. Interrelations of rodents and other wildlife of the range. Calif. Agric. Exp. Stn. Bull. 663: 96-129; 1942.

Howard, W. E.; Childs, H. E. Ecology of pocket gophers with emphasis on *Thomomys bottae mewa*. Hilgardia. 29(7): 277-358; 1959.

Hutchinson, C. B.; Kotok, E. I. The San Joaquin experimental range. Bull. 663. Berkeley, CA: California Agricultural Experiment Station; 1942. 145 p.

Ingles, L. G. The ecology of the mountain pocket gopher (*Thomomys monticola*). Ecology. 33(1): 87-95; 1952.

Julander, O.; Chournos, N. Utah experiments reveal pocket gophers play ruinous role in range reseeding. Natl. Wool Grower. 49(7): 17; 1959.

Julander, O.; Low, J. B.; Morris, O. W. Influence of pocket gophers on seeded mountain range in Utah. J. Range Manage. 12(5): 219-224; 1959.

Julander, O.; Low, J. B.; Morris, O. W. Pocket gophers on seeded Utah mountain range. J. Range. Manage. 22(5): 325-329; 1969.

Kalmbach, E. R. Rodents, rabbits and grasslands. In: Grass: Yearbook of Agriculture for 1948. Washington, DC: U.S. Department of Agriculture; 1948: 248-256.

Kalmbach, E. R. Report of investigations of Grand Mesa gopher project: Denver, CO: U.S. Department of the Interior, Fish and Wildlife Service, Denver Wildlife Research Laboratory; 1950. 3 p. Unpublished M.S. thesis.

Keck, W. M. Great Basin Station, 60 years of progress in range and watershed research. Res. Pap. INT-118. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1972. 35 p.

Larrison, E. J. Pocket gopher and ecological succession in the Wenas region of Washington. Murrelet. 23(2): 34-41; 1942.

Laycock, W. A. An ecological study of the pocket gopher *Thomomys talpoides tennellus* Goldman in the Jackson Hole region of Wyoming. J. Range Manage. 6(6): 461-462; 1953.

Laycock, W. A.; Richardson, B. Long-term effects of pocket gopher control on vegetation and soils of a subalpine grassland. J. Range Manage. 28(6): 458-462; 1975.

McGinnies, W. G. Annual report of the Rocky Mountain Forest and Range Experiment Station. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station; 1947. 69 p.

Moore, A. W.; Reid, E. H. The Dalles pocket gopher and its influence on forage production of Oregon mountain meadows. Circ. 884. Washington, DC: U.S. Department of Agriculture; 1951. 36 p.

Phillips, P. The distribution of rodents in overgrazed and normal grasslands of central Oklahoma. Ecology. 17(4): 673-679; 1936.

Ratliff, R. D.; Westfall, S. E. Non-grazing and gophers lower bulk density and acidity in annual-plant soil. Rep. No. FSRN-PSW-254. Berkeley, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station; 1971. 5 p.

Reid, V. H. Response of small mammal populations to various intensities of livestock grazing in the southern Rocky Mountains Region. Denver, CO: U.S. Department of the Interior, Fish and Wildlife Service, Denver Wildlife Research Center; 1962. 36 p. Annual progress report (mimeo).

Reid, V. H. Small mammal populations in relation to grazing on Black Mesa. Denver, CO: U.S. Department of the Interior, Fish and Wildlife Service, Denver Wildlife Research Center, Wildlife Research Work Unit; 1966. 17 p. Annual progress report.

Reid, V. H. Small mammal populations in relation to grazing on Black Mesa. Denver, CO: U.S. Department of the Interior, Fish and Wildlife Service, Denver Wildlife Research Center, Wildlife Research Work Unit; 1967. 14 p. Annual progress report.

Tester, J. R.; Marshall, W. H. A study of certain plant and animal interrelations on a native prairie in northwestern Minnesota. Occ. Pap. 8. Minneapolis-St. Paul, MN: University of Minnesota, Museum of Natural History; 1961. 51 p.

Tietjen, H. P.; Halvorson, C. H.; Hegdal, P. L.; Johnson, A. M. 2,4-D herbicide, vegetation and pocket gopher relationships: Black Mesa, Colorado. Ecology. 48(4): 634-643; 1967.

Turner, G. T. Responses of mountain grassland vegetation to gopher control, reduced grazing, and herbicide. J. Range Manage. 22(6): 377-383; 1969.

Turner, G. T. Effects of pocket gophers on the range. In: Turner, G. T. (and others), eds. Pocket gophers and Colorado mountain rangeland. Bull. 554S. Fort Collins, CO: Colorado State University, Agriculture Experiment Station; 1973. 90 p.

Turner, G. T.; Hansen, R. M.; Reid, V. H.; Tietjen, H. P.; Ward, A. L. Pocket gophers and Colorado mountain rangeland. Bull. 554S. Fort Collins, CO: Colorado State University, Agriculture Experiment Station; 1973. 90 p.

U.S. Department of Agriculture, Forest Service. Annual report of the Rocky Mountain Forest and Range Experiment Station. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station; 1943.

U.S. Department of the Interior, Fish and Wildlife Service. Do gophers harm rangelands?: contributions to the report of the Division of Wildlife, January 1-December 31, 1967. Denver, CO: U.S. Department of the Interior, Fish and Wildlife Service, Bureau of Sport Fisheries and Wildlife, Denver Wildlife Research Center; 1968: 41 p.

Ward, A. L.; Hegdal, P. L.; Hansen, R. M. Herbicide, vegetation and pocket gopher relationships on Grand Mesa, Colorado. Denver, CO: U.S. Department of the Interior, Fish and Wildlife Service, Denver Wildlife Research Center, Colorado Cooperative Pocket Gopher Project; 1963. 29 p. Annual progress report.

Wilks, B. J. Some aspects of the ecology and population dynamics of the pocket gophers (*Geomys bursarius*) in southern Texas. Texas J. Sci. 15(3): 241-283; 1963.

Williamson, H. G. Habitat improvement evaluation: adaptability of wildlife plants. Oklahoma City, OK: Oklahoma Department of Wildlife Conservation; 1954. 5 p.

Soils (S)

Albrecht, W. Soil fertility and wildlife—cause and effect. In: Transactions, 9th North American Wildlife Conference; 1944 April 24-26; Chicago, IL. Washington, DC: American Wildlife Institute; 9: 19-28; 1944.

Bond, R. M. Rodentless rodent erosion. Soil Conserv. 6(10): 269; 1941.

Branson, F. A.; Miller, R. F.; McQueen, I. S. Plant communities and soil moisture relationships near Denver, Colorado. Ecology. 46: 311-319; 1965.

Carson, C. C. The waterworks laboratory and civil defense. J. NEWWA. 66: 144; 1952.

Davis, W. B.; Ramsey, R. R.; Arendale, J. M., Jr. The distribution of pocket gophers (*Geomys breviceps*) in relation to soils. J. Mammal. 19(4): 412-418; 1938.

Day, A. M. Soil erosion is often caused by burrowing rodents. U.S. Department of Agriculture, Yearbook for 1931. Washington, DC: U.S. Department of Agriculture; 1931: 481-484.

Ellison, L. The pocket gopher in relation to soil erosion on mountain range. Ecology. 27(2): 101-114; 1946.

Frank, E. C.; Brown, H. E.; Thompson, J. R. Hydrology of Black Mesa watersheds, Western Colorado. Gen. Tech. Rep. RM-13. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station; 1975. 11 p.

Grinnell, J. The burrowing rodents of California as agents in soil formation. J. Mammal. 4: 137-149; 1923.

Ratliff, R. D.; Westfall, S. E. Nongrazing and gophers lower bulk density and acidity in annual-plant soil. Res. Note PSW-254. Berkeley, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station; 1971.

Taylor, W. P. Some animal relations to soils. Ecology. 16(2): 127-136; 1935.

Burrow Environment (BE)

Blume, R. R.; Aga, A. *Aphodius* from burrows of a pocket gopher in Brazos County, Texas Coleoptera:Scarabaeidae. Coleopt. Bull. 29(3): 161-162; 1975.

Blume, R. R.; Aga, A. Additional records of aphodius from pocket gopher burrows in Texas USA Coleoptera:Scarabaeidae. Coleopt. Bull. 33(1): 131-132; 1979.

Bond, H. E. Revegetation and disintegration of pocket gopher mounds: on Black Mesa, Colorado. Fort Collins, CO: Colorado State University; 1959. Thesis.

Cartwright, O. L. New *Aphodius* from Texas gopher burrows. Entomol. News. 55(5): 129-135; (6): 146-150; 1944.

Chamberlin, R. V. Two new Lithobiid Chilopods from burrows of the Florida pocket gopher. Entomol. News. 51(2): 48-50; 1940.

Fagerstone, K. A.; Barnes, V. G., Jr.; Anthony, R. M.; Evans, J. Hazards to small mammals associated with underground strychnine baiting for pocket gophers, *Thomomys* spp. In: Proceedings, 9th vertebrate pest conference; 1980 March 4-6; Fresno, CA. Sacramento, CA: Department of Food and Agriculture, Control and Eradication, Vertebrate Pest Conference; 1980: 105-109.

Funderburg, J. B.; Lee, D. S. The amphibian and reptile fauna of pocket gopher (*Geomys*) mounds in central Florida. J. Herpetol. 1: 99-100; 1968.

Gamboa, G. J. Effects of light and air on the trapping response of the pocket gopher, *Thomomys bottae* (Geomyidae). Southwest Nat. 19(4): 444-446; 1975.

Hegdal, P. L.; Gatz, T. A. Hazards to wildlife associated with underground strychnine baiting for pocket gophers. In: Proceedings, 7th vertebrate pest conference; 1976 March 9-11; Monterey, CA. Sacramento, CA: Department of Food and Agriculture, Control and Eradication, Vertebrate Pest Conference; 1976: 258-266.

Hickman, G. C. Burrow system structure of *Pappogeomys castanops* (Geomyidae) in Lubbock County, Texas USA. Am. Midl. Nat. 97(1): 50-58; 1977a.

Hickman, G. C. Geomyid interaction in burrow systems. Texas J. Sci. 29(3-4): 235-244; 1977b.

Hickman, G. C. Burrow system structure of the *Bathyergid cryptomys hottentotus* in Natal South Africa. Z. Saeugetierkd. 44(3): 153-162; 1979.

Hubbell, T. H. A blind cricket-locust (*Typhloceuthophilus floridanus* n. gen. et sp.) inhabitating *Geomys* burrows in peninsula Florida (Orthoptera, Gryllacrididae, Rhaphidorphorinae). Annu. Entomol. Soc. Am. 33(1): 10-32; 1940.

Hubbell, T. H.; Goff, C. C. Florida pocket gopher burrows and their arthropod inhabitats. Q. J. Fla. Acad. Sci. 4: 127-166; 1939.

Kennerly, T. E., Jr. Microenvironmental conditions of the pocket gopher burrow. Texas J. Sci. 16(4): 395-441; 1964.

Laycock, W. A. The initial pattern of revegetation of pocket gopher mounds. Ecology. 39(2): 346-351; 1958.

Lechner, A. J. Respiratory adaptations in burrowing pocket gophers from sea level and high altitude. J. Appl. Physiol. 41(2): 168-173; 1976.

Miller, M. A. Burrows of the Sacramento Valley pocket gopher in flood-irrigated alfalfa fields. Hilgardia. 26(8): 431-452; 1957.

Murray, D. F. Gravel mounds at rocky flats, Colorado. Mountain Geol. 4(3): 99-107; 1967.

Ross, B. A.; Tester, J. R.; Breckenridge, W. J. Ecology of mima-type mounds in northwestern Minnesota. Ecology. 49(1): 172-177; 1968.

Ross, E. S. New Histeridae (Coleoptera) from the burrows of the Florida pocket gopher. Annu. Entomol. Soc. Am. 33(1): 1-9; 1940.

Ross, E. S. *Onthophilus kirni* new species, and two other noteworthy Histeridae from burrows of a Texas pocket gopher. Entomol. News. 55(5): 115-118; 1944.

Scheffer, T. H. Excavation of a runway of the pocket gopher (*Geomys bursarius*). In: Transactions, 1940 Kansas Academy of Science: 72nd Annual Meeting; 1940 March 28-30; Wichita, KA. Topeka, KA: Kansas Academy of Science; 1940: 473-478.

Scheffer, T. H. Burrow associations of small mammals. Murrelet. 26: 24-26; 1945.

Smith, C. F. A burrow of the pocket gopher *Geomys bursarius* in eastern Kansas. Kansas Academy of Science, Transactions 51(3): 313-315; 1948.

Vaughan, T. A. Vertebrates inhabiting pocket gopher burrows in Colorado. J. Mammal. 42(2): 171-174; 1961.

Damage to Forest Land (DTF)

Anon. Multimillion dollar menu. Weyerhaeuser News. 41: 17-19; 1959 July.

Barnes, V. G., Jr. Pocket gophers and reforestation: a problem analysis. Special Sci. Rep.-Wildl. No. 155. Denver, CO: U.S. Department of the Interior, Fish and Wildlife Service, Denver Wildlife Research Center, Forest Animal Damage Unit; 1973. 18 p.

Barnes, V. G., Jr. Survival and growth of ponderosa pine seedlings injured by pocket gophers. Tree Planters Notes 29(2): 20-23; 1979.

Black, H. C.; Dimock, E. J.; Dodge, W. E.; Lawrence, W. H. Survey of animal damage on forest plantations in Oregon and Washington. In: Transactions, 34th North American wildlife and natural resources conference; 1969 March 3-5; Washington, DC. Washington, DC: Wildlife Management Institute; 1969: 34: 388-408.

Buchner, R.; Rorabaugh, J. The mountain pocket gopher (*Thomomys monticola*) and some implications for timber management. Placerville, CA: U.S. Department of Agriculture, Forest Service, Eldorado National Forest; 1979. 36 p.

Canutt, P. R. Brief case history of several different reforestation situations in region six. Portland, OR: U.S. Department of Agriculture, Forest Service, Regional Forester's Office; 1967. 21 p.

Canutt, P. R. Relative damage by small mammals to reforestation in Washington and Oregon. In: Black, H. C., ed. Proceedings, symposium on wildlife and reforestation in the Pacific Northwest; 1968; Corvallis, OR. Corvallis, OR: Oregon State University, School of Forestry; 1969: 55-59.

Canutt, P. R. Pocket gopher problems and control practices on National Forest lands in the Pacific Northwest Region. In: Proceedings, 4th vertebrate pest conference; 1970 March 3-5; West Sacramento, CA. Davis, CA: University of California, Department of Agricultural Zoology, Vertebrate Pest Commission; 1970: 120-125.

Capp, J. C. Increasing pocket gopher problems in reforestation. In: Proceedings, 7th vertebrate pest conference; 1976 March 9-11; Monterey, CA. Sacramento, CA: Department of Food and Agriculture, Control and Eradication, Vertebrate Pest Conference; 1976: 221-228.

Crouch, G. L. Animal damage to conifers on national forests in the Pacific Northwest region. Res. Bull. PNW-28. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1969. 13 p.

Crouch, G. L. Susceptibility of ponderosa, jeffrey and lodgepole pines to pocket gophers. Northwest Sci. 45(4): 252-256; 1971.

Davidson, E. D.; Barbour, M. G. Germination establishment and demography of coastal bush lupine *Lupinus arboreus* at Bodega Head, California, USA. Ecology. 58(3): 592-600; 1977.

Dingle, R. W. Pocket gophers as a cause of mortality in eastern Washington pine plantations. J. For. 54(12): 832-835; 1956.

Evans, J.; (and others). Survey of forest-animal damage in southwestern Oregon. Olympia, WA: U.S. Department of the Interior, Fish and Wildlife Service; 1981. 31 p. Job completion report, forest animal research project.

Hermann, R. K. Survival of planted ponderosa pine in southern Oregon. Res. Pap. 2. Corvallis, OR: Oregon State University, Forest Research Lab; 1965. 32 p.

Hooven, E. F. Pocket gopher damage on ponderosa pine plantations in southwestern Oregon. J. Wildl. Manage. 35(2): 346-353; 1971.

Ingles, L. G. The ecology of the mountain pocket gopher *Thomomys monticola*. Ecology. 33(1): 87-95; 1952.

Kuck, L. E. The effects of the northern pocket gopher on reforestation: activity and movement. Moscow, ID: University of Idaho; 1969. 49 p. Thesis.

Lantz, D. E. Pocket gophers as enemies of trees. In: Yearbook for 1909. Washington, DC: U.S. Department of Agriculture; 1909: 209-218.

Lawrence, W. H.; Kverno, N. B.; Hartwell, H. D. Guide to wildlife feeding injuries on conifers in the Pacific Northwest. Portland, OR: Western Forestry and Conservation Association; 1961. 44 p.

Miles, W. R. Hazard of growing Christmas trees. Conserv. Volunteer. 25(144): 10-15; 1961.

Miles, W. R.; Krefting, K. W.; Hansen, H. L. Pocket gopher damage in red and scotch pine Christmas tree plantations in central Minnesota. Minn. For. Note No. 110. St. Paul, MN: University of Minnesota, School of Forestry; 1961. 2 p.

Minore, D. The Dead Indian Plateau: A historical summary of forestry observations and research in a severe southwestern Oregon environment. Gen. Tech. Rep. PNW-72. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1978. 23 p.

Moore, A. W. Wild animal damage to seed and seedlings on cutover Douglas-fir lands of Oregon and Washington. Tech. Bull. 706. Washington, DC: U.S. Department of Agriculture; 1940. 28 p.

Moore, A. W. The pocket gopher in relation to yellow pine reproduction. J. Mammal. 24(2): 271-272; 1943.

Oregon Department of Forestry. Lowly gopher adds reforestation woes. The Forest Log. 31: 2; 1961.

Tevis, L., Jr. Pocket gophers and seedlings of red fir. Ecology. 37(2): 379-381; 1956.

Tietjen, H. P. Control of pocket gophers. In: Turner, G. T. (and others), eds. Pocket gophers and Colorado mountain rangeland. Bull. 554S. Fort Collins, CO: Colorado State University, Agriculture Experiment Station; 1973: 73-82.

Tietjen, H. P. 2,4-D vegetation and pocket gophers. In: Turner, G.T. (and others), eds. Pocket gophers and Colorado mountain rangeland. Bull. 554S. Fort Collins, CO: Colorado State University, Agriculture Experiment Station; 1973: 63-71.

U.S. Department of Agriculture. Activity review report, pocket gopher-reforestation activity review: West. Reg. 4 and 6. Washington, DC: U.S. Department of Agriculture; 1979. 26 p.

U.S. Department of Agriculture, Forest Service. Control of pocket gopher in Texas. Washington, DC: U.S. Department of Agriculture, Forest Service; 1972. 15 p. Draft environmental impact statement.

Wight, H. M. Breeding habits and economic relations of The Dalles pocket gopher. J. Mammal. 11: 40-48; 1930.

Williamson, D. M.; Minore, D. Survival and growth of planted conifers on the Dead Indian Plateau east of Ashland, Oregon. Res. Pap. PNW-242. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1978. 15 p.

Working Group of the Northwest Pocket Gopher Committee. Survey of pocket gopher research in the western United States 1975. Portland, OR: Western Forestry and Conservation Association, Oregon-Washington Silvicultural Council, Northwest Pocket Gopher Committee; 1975. 5 p.

Working Group of the Northwest Forest Pocket Gopher Committee. Survey of pocket gopher damage to conifers in the Pacific Northwest, 1975. Portland, OR: Western Forestry and Conservation Association, Oregon-Washington Silvicultural Association, Northwest Pocket Gopher Committee; 1976. 7 p.

Damage to Rangeland, Agricultural Land, and Gardens (DTR)

Joki, W. M. Gophers or gardens? Org. Gard. 10(1): 19-22; 1946.

Jones, M. A. The pocket gopher, night raider, works alone. Better Homes and Gardens. 11: 22, 38-39; 1932 September.

Lantz, D. E. Rodent pests of the farm. Farmer's Bull. 932. Washington, DC: U.S. Department of Agriculture; 1918. 23 p.

Moore, P.; Skou, S.; Naer, E. The gopher menace. Calif. Citrog. 41: 273-275; 1956.

Moore, P. W. Underground problems brought to light. Calif. Citrog. 40: 251-252; 1955.

Morris, P. A. Circumstantial evidence. Better Homes and Gardens. 16(1): 104-107; 1937.

Scheffer, T. H. Concerning the pocket gopher and destructive habits. Better Fruit. 10(10): 7-8; 1916.

Scheffer, T. H. Habits and economic status of the pocket gophers. Tech. Bull. 224. Washington, DC: U.S. Department of Agriculture; 1931. 27 p.

Scheffer, T. H.; Garlough, F. E. Rodents and moles as pests in bulb plantings. Circ. 381. Washington, DC: U.S. Department of Agriculture; 1936. 16 p.

Silver, J. Rodent enemies of fruit and shade trees. J. Mammal. 5(3): 165-173; 1924.

Sparks, H. Money down the hole. Calif. Citrog. 38(6): 20-22; 1952.

Steinburg, H. M. The western gardeners' public enemy No. 1. Am. Homes. 21: 97; 1939 March.

Stiles, C. F. Don't let gophers ruin your alfalfa. Farmer - Stockman 60(1): 52; 1947.

Wight, H. M. Breeding habits and economic relations of The Dalles pocket gopher. J. Mammal. 11: 40-48; 1930.

Wisor, D. R. Your underground enemy. Calif. Citrog. 30: 319; 1945.

Damage to Buried Materials (DBM)

Connolly, R. A.; Landstrom, R. E. Gopher damage to buried cable materials. Mater. Res. Stand. 9(12): 13-18; 1969.

Howard, W. E. Tests of pocket gophers gnawing electric cables. J. Wildl. Manage. 17(3): 296-300; 1953.

Damage Control (DC)

Anon. Directions for destroying pocket gophers. Bi-175. Washington, DC: U.S. Department of Agriculture, Bureau of Biological Survey; 1919.

Anon. Killing gophers. Calif. Cultivator. 61: 390; 1923.

Anon. Killing gophers. Calif. Cultivator. 68: 539; 1927.

Anon. Stop the mound builders: use poison baits to control pocket gophers. Wallace's Farmer 55: 1004; 1930.

Anon. Gas chambers for gophers. Reclam. Era. 38(2): 27; 1952.

Agular, Dias A. Control de la Tuza (*Geomys* sp.). Fitolfilo. 12(24): 5-15; 1959.

Allen, A. W.; Johnson, S. J.; Keller, B. L. Success of pocket gopher control in reducing tree mortality. St. Anthony, ID: U.S. Department of Agriculture, Forest Service, Targhee National Forest; 1978. 22 p.

Altman, R. W. Controlling pocket gophers. Extension Facts No. 9001. Stillwater, OK: Oklahoma State University; 1966. 1 p.

Anthony, R. M.; Barnes, V. G., Jr. Evaluation of vexar tubes and increased stocking rates to alleviate reforestation losses by pocket gophers. Washington, DC: U.S. Department of the Interior, Fish and Wildlife Service; 1980. 5 p. Annual progress report, forest ADC research project.

Anthony, R. M.; Barnes, V. G., Jr.; Evans, J. Vexar plastic netting to reduce pocket gopher depredation of conifer seedlings. In: Proceedings, 8th vertebrate pest conference; 1978 March 7-9; Sacramento, CA. Sacramento, CA: Department of Food and Agriculture, Control and Eradication, Vertebrate Pest Conference; 1978: 138-144.

Atzert, S. P. A review of sodium monofluroacetate (compound 1080); its properties, toxicology and use in predator and rodent control. Washington, DC: U.S. Department of the Interior, Fish and Wildlife Service, Report by the Bureau of Sport Fisheries and Wildlife; 1971. 36 p.

Bare, Os. S.; Sooter, C. A. Pocket gopher control. Agric. Ext. Econ. 1544. Lincoln, NB: Nebraska Agricultural Extension Service; 1946. 47 p.

Barnes, V. R-6 silviculture workshop: pocket gopher damage control-state of the art. Colville, WA: U.S. Department of Agriculture, Forest Service, Colville National Forest; 1978. 2 p.

Barnes, V. G., Jr.; Fagerstone, K. A.; Anthony, R. M.; Evans, J. Effects of strychnine baiting in forest plantations on pocket gophers and other small mammals. Denver, CO: U.S. Department of the Interior, Fish and Wildlife Service, Denver Wildlife Research Center. 1980. 25 p. Job completion report, Forest ADC. Unpublished.

Barnes, V. G.; Martin, P.; Tietjen, H. P. Pocket gopher control on Oregon ponderosa pine plantations. J. For. 68(7): 433-435; 1970.

Baumgartner, D. M. Suppliers of pest repellents and traps. Pullman, WA: Washington State University; Cooperative Extension Service, College of Agriculture; 1972. Extension mimeo E.M. 3538.

Becker, E. M. Gopher control by the poisoning method. Calif. Citrog. 28: 182-183; 1943.

Becker, E. M. Vigil and vigor vanish vexatious varmit! Calif. Citrog. 31: 494; 1946.

Bell, W. B. 1925. Destroying pocket gophers. U.S. Golf Assoc. Bull. Green Sec. 5: 36-38; 1925 February.

Bell, W. B.; Piper, S. F. Extermination of ground squirrels, gophers and prairie dogs in N. Dakota. Circ. 4. Fargo, ND: North Dakota Agricultural Experiment Station, Agricultural College; 1915. 11 p.

Besemer, S. T. Mechanical gopher control on golf courses. Calif. Turfgrass Cult. 14(2): 16; 1964.

Birch, L. E. Guidelines for effective contract control of the Rocky Mountain pocket gopher. St. Anthony, ID: U.S. Department of Agriculture, Forest Service, Targhee National Forest, Ashton Ranger District; 1978. 46 p.

Black, H. C.; Hooven, E. F. Effects of herbicide-induced habitat changes on pocket gophers in southwestern Oregon. In: Proceedings, 29th Annual California Weed Conference. Sacramento, CA: California Weed Conference; 29: 119-127; 1977.

Blonk, H. Gassing the gopher: gas-work takes the guesswork out of killing gophers on (irrigation) canal banks. Reclam. Era. 37: 194-196; 1951.

Borrecco, J. E. Controlling damage by forest rodents and lagomorphs through habitat manipulation. In: Proceedings, 7th vertebrate pest conference; 1976 March 9-11; Monterey, CA. Sacramento, CA: Department of Food and Agriculture, Control and Eradication, Vertebrate Pest Conference; 1976: 203-210.

Bristol, W. M. Getting gophers and squirrels. Pacific Rural Press. 87: 12; 1914.

Brock, E. M. Toxicological feeding trials to evaluate the hazard of secondary poisoning to gopher snakes *Pituophis catenifer*. Copeia. 2: 244-245; 1965.

Burnett, W. L. Pocket gophers with suggestions for control. Circ. 23. Fort Collins, CO: Office of the State Entomologist; 1917. 8 p.

Campbell, D. L.; Evans, J. "Vexar" seedling protectors to reduce wildlife damage to Douglas-fir. Leafl. 508. Washington, DC: U.S. Department of the Interior, Fish and Wildlife Service; 1975. 11 p.

Canutt, P. R. New developments in gopher control. In: Proceedings, 1968 Western Reforestation Coordination Committee: annual meeting; 1968 December 3; San Francisco, CA. Portland, OR: Western Forestry and Conservation Association; 1968: 24-27.

Canutt, P. R. Development and operation of the forestland and burrow builder. In: Black, H. C., ed. Proceedings, symposium on wildlife and reforestation in the Pacific Northwest; 1968; Corvallis, OR. Corvallis, OR: Oregon State University, School of Forestry; 1969: 77-79.

Canutt, P. R. Pocket gopher problems and control practices on National Forest lands in the Pacific Northwest Region. In: Proceedings, 4th vertebrate pest conference; 1970 March 3-5; West Sacramento, CA. Davis, CA: University of California, Department of Agricultural Zoology, Vertebrate Pest Commission; 1970: 120-125.

Caroline, M. The pocket gopher burrow builder. Texas Agric. Prog. 6(4): 6-7; 1960.

Christensen, R. D. Environmental rodent control: summary report. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Region, Range Improv. Notes. 17(3): 3; 1972.

Conrad, P. W.; McLaughlin, J. M. Can pocket gophers be controlled by anhydrous ammonia (NH^3) on mountain rangelands? U.S. Department of Agriculture, Forest Service, Intermountain Region, Range Improv. Notes. 16(4): 1-4; 1971.

Cook, J. B. Protecting young trees from gophers. Calif. Citrog. 39: 72, 89-90; 1954.

Copeman, Vander R. Poisoning by strychnine. J. For. Med. 4(4): 180-185; 1957.

Crabtree, D. G. Review of current vertebrate pesticides. In: Proceedings, 1st vertebrate pest control conference; 1962 February 6-7; Sacramento, CA. Elizabeth, NJ: National Pest Control Association; 1962: 326-362.

Crouch, G. L. Atrazine improves survival and growth of ponderosa pine threatened by vegetative competition and pocket gophers. For. Sci. 25(2): 99-111; 1979.

Crouch, G. L.; Frank, L. R. Poisoning and trapping pocket gophers to protect conifers in northeastern Oregon: forest pest control, rodent control. Res. Pap. PNW-261. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1979. 8 p.

Crouch, G. L.; Hafenstein, E. Atrazine promotes ponderosa pine regeneration. Res. Pap. PNW-309. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1977: 1-7.

Crouch, W. E. Pocket gopher control. Farmer's Bull. No. 1709. Washington, DC: U.S. Department of Agriculture; 1933. 21 p.

Crouch, W. E. Pocket gopher control. Conservation Bulletin No. 23. Washington, DC: U.S. Department of the Interior, Fish and Wildlife Service; 1942. 20 p.

Cummings, M. W. Control of pocket gophers. In: Proceedings, 1st vertebrate pest control conference; 1962 February 6-7; Sacramento, CA. Elizabeth, NJ: National Pest Control Association; 1962: 113-125.

Dixon, J. Control of the pocket gopher in California. Bull. No. 281. Berkeley, CA: California Agricultural Experiment Station; 1917. 13 p.

Dixon, J. Control of the pocket gophers in California. Bull. No. 340. Berkeley, CA: California Agricultural Experiment Station; 1922: 337-350.

Dixon, J. Control of pocket gophers and moles in California. Circ. 29. Berkeley, CA: California Agriculture Experiment Station; 1929. 16 p.

Dixon, J. Methods for controlling pocket gophers and moles in California (excerpts). Calif. Citrog. 17: 331; 1932.

Driscoll, R. S. Repellents reduce deer browsing on ponderosa pine seedlings. Res. Note PNW-5. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1963. 8 p.

Eadie, W. R. Animal control in field, farm and forest. New York: MacMillan; 1945. 257 p.

Ellis, G. R. Plastic mesh tubes constrict black walnut root development after two years. Tree Planters Notes. 23(3): 27-28; 1972.

Evans, J.; Hegdall, P. L.; Griffith, R. E., Jr. Methods of controlling jack rabbits. In: Proceedings, 4th vertebrate pest conference; 1970 March 3-5; West Sacramento, CA. Davis, CA: University of California, Department of Agricultural Zoology, Vertebrate Pest Commission; 1970: 109-116.

Fagerstone, K. A.; Barnes, V. G., Jr.; Anthony, R. M.; Evans, J. Hazards to small mammals associated with underground strychnine baiting for pocket gophers *Thomomys* spp. In: Proceedings, 9th vertebrate pest conference; 1980 March 4-6; Fresno, CA. Sacramento, CA: Department of Food and Agriculture, Control and Eradication, Vertebrate Pest Conference; 1980: 105-109.

Frank, L. Gopher control analysis report, fiscal year 1973. Bend, OR: U.S. Department of Agriculture, Forest Service, Deschutes National Forest; 1975: 11 p. Report 2650, Control December 15, 1972. 11 p.

Gabrielson, I. N. Controlling rodent and other small animal pests in Oregon. Ext. Bull. 335. Corvallis, OR: Oregon Agricultural College; 1921. 19 p.

Gabrielson, I. N. Controlling rodents and other small animal pests in Oregon. Ext. Bull. 629. Corvallis, OR: Oregon State College; 1944. 24 p. (Revised, Hansen, G. H., ed. 1957. 31 p.)

Gamboa, G. J. Effects of light and air on the trapping response of the pocket gopher *Thomomys bottae* Geomyidae. Southwest Nat. 19(4): 444-446; 1975.

Garlough, F. E. Research studies in the control of destructive mammals. Leaflet 91. Washington, DC: U.S. Department of Agriculture, Bureau of Biological Survey; 1937. 12 p.

Garlough, F. E.; Ward, J. C. Possibilities of secondary poisoning of birds and mammals. Science. 75: 335-337; 1932.

Golovanova, E.; Egorava, L. A prospective pesticide in the control of gophers. Zasheh. Rast. ot Ured. i Boleznei. 1: 21; 1965. In Russian.

Haigh, S. Poison gophers and rats. Pacific Rural Press. 90: 65; 1915.

Handley, M. H. County programs for vertebrate pest control in California (ground squirrel, pocket gopher, and meadow mouse). In: Proceedings, 8th vertebrate pest conference; 1978 March 7-9; Sacramento, CA. Sacramento, CA: Department of Food and Agriculture, Control and Eradication, Vertebrate Pest Conference; 1978: 60-62.

Hansen, R. M. New dispenser aids gopher control. Pamphlet 1-S. Fort Collins, CO: Colorado State University, Agriculture Experiment Station; 1956. 8 p.

Hanson, W. O.; Smith, J. G. Significance of forage quality as a tool in wildlife management. In: Range and wildlife habitat evaluation - a research symposium. Misc. Publ. No. 1147. Washington, DC: U.S. Department of Agriculture; 1970: 25-31.

Hayne, D. W. Zinc phosphide: its toxicity to pheasants and effect of weathering upon its toxicity to mice. East Lansing, MI: Michigan Agriculture Experiment Station, Quarterly Bull. 33: 412-425; 1951.

Hegdal, P. L.; Gatz, T. A. Hazards to wildlife associated with underground strychnine baiting for pocket gophers. In: Proceedings, 7th vertebrate pest conference; 1976 March 9-11; Monterey, CA. Sacramento, CA: Department of Food and Agriculture, Control and Eradication, Vertebrate Pest Conference; 1976: 258-260.

Hickling, W. C.; Colberg, W. J. Pocket gopher control with the mechanical burrowing machine. Ext. Circ. A-368. Fargo, ND: North Dakota Agricultural College; 1962. 6 p.

Hines, T.; Dimmick, R. W. The acceptance by bobwhite quail of rodent baits dyed and treated with zinc phosphide. In: Proceedings, 1970 Southeastern Association of Game and Fish Commissioners: 24th annual conference; 1970 September 27-30; Atlanta, GA. Nashville, TN: Wildlife Resources Agency, Ellington Agricultural Center; 1970: 201-205.

Hoffer, M. C.; Passof, P. C.; Krohn, R. Field evaluation of DRC-714 for deermouse control in a redwood habitat. J. For. 67(3): 158-159; 1969.

Hood, G. A. Zinc phosphide—a new look at an old rodenticide for field rodents. In: Marsh, R. E., ed. Proceedings, 5th vertebrate pest conference; 1972 March 7-9; Fresno, CA. Davis, CA: University of California, Department of Animal Physiology, Vertebrate Pest Conference; 1972: 85-92.

Hornbeck, R. Hand gopher control. In: Proceedings, 1st reforestation workshop; 1968 March 6-8; Portland, OR. Portland, OR: U.S. Department of Agriculture, Forest Service, Region 6; 1968: 235-245.

Howard, W. E. Rodent control on California ranges. J. Range Manage. 6(6): 423-434; 1953.

Hull, A. C., Jr. Effect of spraying with 2,4-D upon abundance of pocket gophers in Franklin Basin, Idaho. J. Range Manage. 24: 230-232; 1971.

Ivan, O. A.; Levin, L. V.; Skalinov, S. V. Gliftor in the control of gophers. Zashch. Rast. ot Ured. i Bolzenei. 12: 10-11; 1964. In Russian.

Janda, J.; Bosseova, M. The toxic effect of zinc phosphide baits on partridges and pheasants. J. Wildl. Manage. 34(1): 220-223; 1970.

Johnson, D. R. Effects of range treatment with 2,4-D on food habits of rodents. Ecology. 45(2): 241-249; 1964.

Johnson, D. R.; Hansen, R. M. Effects of range treatment with 2,4-D on rodent populations. J. Wildl. Manage. 33(1): 125-132; 1969.

Johnson, W. V. Rabbit control. In: Proceedings, 2nd vertebrate pest conference; 1964 March 4-5; Anaheim, CA. Davis, CA: University of California, Department of Animal Physiology; 1964: 90-96.

Kalmbach, E. R. "Ten eighty" a war produced rodenticide. Science. 102: 232-233; 1945.

Kalmbach, E. R.; Welch, J. F. Color of rodent baits and their value in safeguarding birds. J. Wildl. Manage. 10(4): 353-360; 1946.

Keith, J. O.; Hansen, R. M.; Ward, A. L. Effect of 2,4-D on abundance and foods of pocket gophers. J. Wildl. Manage. 23(2): 137-145; 1959.

Kepner, R. A.; Howard, W. E. Mechanical gopher-bait applicator for pastures and open fields. Calif. Agric. 14(3): 7-14; 1960.

Kepner, R. A.; Howard, W. E.; Cummings, M. W.; Brock, E. M. Construction and use of U. C. mechanical gopher-bait applicator. Davis, CA: University of California, Agriculture Extension Service; 1961. 8 p.

Kepner, R. A.; Howard, W. E.; Cummings, M. W.; Brock, E. M. U. C. mechanical gopher-bait applicator. Davis, CA.: University of California, Agriculture Extension Service; 1962.

Kepner, R. A.; Howard, W. E.; Cummings, M. W. Mechanical application of gopher bait. American Society of Agricultural Engineers, Transactions 8(3): 335-337; 1965.

Kimbal, J.; Poulson, T. A.; Savage, W. F. An observation of environmental rodent control. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Region; Range Improvement Notes. 15(2); 1970.

Klinger, G.; Hafenstein, E. L. Machine gopher control on the Winema National Forest. In: Proceedings, 1st forest reforestation workshop; 1968 March 6-8; Portland, OR. Portland, OR: U.S. Department of Agriculture, Forest Service, Region 6; 1968: 29-34.

Lantz, D. E. Destroying gophers and prairie dogs. Kansas State Board of Agriculture; Q. Rep. 21(81): 325-331; 1902.

Lantz, D. E. Directions for destroying pocket gophers. Circ. No. 52, rev. ed. Washington, DC: U.S. Department of Agriculture, Bureau of Biological Survey; 1908: 1-4.

Lawrence, W. H. Wildlife damage control problems on Pacific Northwest tree farms. In: Transactions, 23rd North American Wildlife Conference; 1958 March 3-5; St. Louis, MO. Washington, DC: Wildlife Management Institute; 1958: 146-151.

Lynch, G. M. The effect of strychnine control on nest predators of dabbling ducks. J. Wildl. Manage. 36(2): 436-440; 1972.

Marsh, R. E.; Plesse, L. F. Semipermanent anticoagulant baits. California Department of Agriculture, The Bulletin. 49(3): 195-197; 1960.

Marsh, R. E.; Cummings, M. W. Pocket gopher control with mechanical bait applicator. Pub. AXT-261. Berkeley, CA: University of California, Agricultural Extension Service; 1968. 8 p.

Marsh, R. E.; Cummings, M. W. Pocket gopher control with mechanical bait applicator. Leaflet 2699. Berkeley, CA: Cooperative Extension, U.S. Department of Agriculture and University of California; 1976. 7 p.

Martin, W. E. Toxicants commonly used in the animal damage control programs of the Division of Wildlife Services. Washington, DC: U.S. Department of the Interior, Fish and Wildlife Service; 1971. 26 p.

McKeever, S. Compound 1080 and forest regeneration: characteristics of the poison in relation to bait shyness, poison shyness, toxicity to rodents and phytotoxicity to conifer seed. Sacramento, CA: California Department of Conservation, Division of Forest Reproduction; 1964. 18 p.

Mickel, C. E. Poisoning pocket gophers. St. Paul, MN: University of Minnesota, Agricultural Experiment Station; 1923. 4 p.

Mickel, G. Pocket gopher in Colorado. Fort Collins, CO: Colorado Agriculture College; 1957. 6 p.

Miller, M. A. Eradication of pocket gophers; comparative field tests demonstrate best poison, baits and dosages for practical gopher control. Calif. Agric. 4(12): 8-10; 1950.

Miller, M. A. Experimental studies on poisoning pocket gophers. Hilgardia. 22(4): 131-166; 1953.

Miller, M. A. Poison gas tests on gophers. Calif. Agric. 8(10): 7-14; 1954.

Miller, M. A.; Howard, W. E. Size of bait for pocket gopher control. J. Wildl. Manage. 15(1): 62-68; 1951.

Miller, M. A.; Hansen, R. S. New developments in pocket gopher control. Cattle Guard. 2: 32-33; 1956.

Moore, A. W.; Ward, J. C. The effect of altitude on the action of drugs. I. Strychnine. J. Am. Pharm. Assoc. 24(6): 460-464; 1935.

Morgan, D. N., ed. How Morrison gets gophers. Pacific Rural Press. 108: 482; 1924.

Murton, R. K. The use of biological methods in the control of vertebrate pests. In: Jones, P.; Solomon, M. E., eds. Biology in pest disease control: proceedings, 13th symposium of the British Ecological Society; 1972 January 4-7; Oxford. Oxford: Blackwell Scientific Publications; 1974: 211-233. 398 p.

Neff, J. B. Poison for gophers. Calif. Cultivator. 26: 149; 1906.

de Ong, E. R. Gopher control. Calif. Cultivator. 54: 5; 1920.

Packer, P. E. Site preparation in relation to environmental quality. In: Maintaining productivity of forest soils: Annual meeting of western reforestation coordinating committee; 1971 November 30-December 1; Portland, OR. Portland, OR: Western Forestry and Conservation Association; 1971: 23-27.

Palotas, G. New method for gopher control (Gas cartridge) (in Hungarian). Magyar Mezogazdasag. 23(8): 14-15; 1968.

Parten, H. L. Controlling pocket gophers. Agric. Ext. Folder 75. St. Paul, MN: University of Minnesota, Agricultural Extension; 1939. 6 p.

Parten, H. L.; Issac, R. Controlling pocket gophers. Agric. Ext. Folder 75. St. Paul, MN: University of Minnesota, Agricultural Extension; 1951. 8 p.

Pehrson, J. E. Growers war with gophers. Calif. Citrog. 49(11): 434; 1964.

Pehrson, J. E. Bait machines go for gophers. Western Fruit Grower. 19(7): 19; 1965.

Radosevich, S. R.; Howard, W. E.; Marsh, R. E. Preliminary report on: effects of vegetative manipulation and animal damage control in the regeneration of conifer seedlings: U.S. Department of Agriculture, Forest Service-University of California-Davis contract supplement -41. Davis, CA: University of California, Department of Botany; 1981. 12 p.

Ray, V. Response of pocket gophers (*Thomomys mazama*) to baiting with strychnine oats plus attractant in polyethylene bags. Tech. Rep. Pocket Gopher 042-4102/78/84. Centralia, WA: Weyerhaeuser Company, Western Forestry Research Center; 1978. 5 p.

Richens, V. B. An evaluation of control on the Wasatch pocket gopher. J. Wildl. Manage. 29(3): 413-425; 1965.

Richens, V. B. An evaluation of control on the pocket gopher (*Thomomys talpoides*) on the Cache National Forest. Logan, UT: Utah State University; 1967a. Dissertation.

Richens, V. B. Gophacide, latest findings from studies of this new rodenticide. Pest Control. 35(9): 28, 30, 50; 1976b.

Richens, V. B. The status and use of gophacide. In: Proceedings, 3rd vertebrate pest conference; 1968 March 7-9; San Francisco, CA. Davis, CA: University of California, Department of Agricultural Zoology, vertebrate pest conference; 1968: 118-125.

Robison, W. H. Acute toxicity of sodium monofluoroacetate to cattle. J. Wildl. Manage. 34(3): 647-648; 1970.

Rosedale, D. O. New device aids in gopher control. Western Fruit Grower. 15(7): 29; 1961.

Rosedale, D. O.; Cummings, M. W. Mechanical bait applicator controls gophers in citrus. Calif. Agric. 16(9): 14; 1962.

Rost, G. R. Effectiveness of gas cartridges for pocket gopher control. Boise, ID: U.S. Department of the Interior, Fish and Wildlife Service, Animal Damage Control; 1978. 6 p.

Rudd, R. L.; Genelly, R. E. Pesticides: their use and toxicity in relation to wildlife. Game Bull. No. 7. Sacramento, CA: California Department of Fish and Game; 1956. 209 p.

Salmon, T. P.; Marsh, R. E. Age as a factor in rodent susceptibility to rodenticides. In: Beck, J. R., ed. Vertebrate pest control and management materials: proceedings, 2nd symposium on test methods for vertebrate pest control and management materials; 1978 March 10; Monterey, CA. Philadelphia, PA: American Society for Testing and Materials; 1979: 84-100. ASTM STP 680.

Sanders, G. E. Gopher control by means of calcium cyanide. Agric. Gaz. Can. 8: 628-629; 1921.

Sargent, A. B.; Peterson, B. R. Pocket gopher control in Minnesota with the mechanical burrow builder. Washington, DC: U.S. Department of the Interior, Fish and Wildlife Service, Bureau of Sport Fisheries and Wildlife, Branch of Predator and Rodent Control; 1963. 18 p.

Saskatchewan; Chief Game Guardian. The effect of gopher poison on prairie chickens. BI-1028. Washington, DC: U.S. Department of Agriculture, Bureau of Biological Survey; 1918: 20-21.

Schroeder, M. H. Gophacide, a candidate for control of Ord's kangaroo rat. J. Wildl. Manage. 31(2): 339-341; 1967.

Skinner, W. W. Extermination of pocket gophers and ants. Ariz. Agric. Exp. Stn. Bull. 45: 227-230; 1902.

Slawson, H. H. Baits vs. gas for gophers. Pest Control. 22(12): 16; 1954.

Spencer, D. A. Chemical controls as a management measure. J. For. 60(1): 28-30; 1962.

Storer, T. I. Control of injurious rodents in California. Circ. 79. Berkeley, CA: California Agricultural Extension Service; 1938. 62 p.

Storer, T. I. Field rodent control by destruction of burrows. J. Wildl. Manage. 9(2): 156-157; 1945.

Storer, T. I. Control of field rodents in California. Circ. 138. Berkeley, CA: California Agricultural Extension Service; 1947. 51 p.

Storer, T. I. Controlling field rodents in California. Circ. 434. Berkeley, CA: California Agricultural Extension Service; 1953. 47 p. (Revised 1958. 50 p.)

Storer, T. I. Controlling pocket gophers and moles in gardens. Leaflet 135. Berkeley, CA: University of California, Agricultural Extension; 1961.

Storer, T. I.; Mann, M. P. Bibliography of rodent control. Rep. 182. Washington, DC: National Research Council, Insect Control Commission; 1946. 324 p.

Storer, T. I.; Mann, M. P. Bibliography of rodent control (first supplement) and bibliography of ANTU. Rep. 1. Washington, DC: U.S. Public Health Service, National Institute of Health; 1948. 76 p.

Tasker, J. B. Pocket gopher control in forest plantations. J. For. 49(2): 130-131; 1950.

Texas Agricultural College. Thumbs down on pocket gophers with poisoned grain. Ext. Leaflet 192. College Station, TX: Texas Agricultural College; 1954. 1 p.

Tietjen, H. P. 2,4-D, vegetation, and pocket gophers. In: Turner, G. T. (and others), eds. Pocket gophers and Colorado mountain rangeland. Bull. 544S. Fort Collins, CO: Colorado State University, Agriculture Experiment Station; 1973: 63-72.

Tigner, J. R.; Landstrom, R. E. Chemical protection methods progress. Electron. Packag. Prod. 8(4): 120-134; 1968.

Tissot, A. N. Control of the pocket gopher or "salamander". Circ. S-87. Gainesville, FL: Florida Agricultural Experiment Station; 1955. 10 p.

Tucker, R. K.; Crabtree, D. G. Handbook of toxicity of pesticides to wildlife. Resour. Publ. No. 84. Washington, DC: U.S. Department of the Interior, Fish and Wildlife Service; 1970. 131 p.

U.S. Department of Agriculture. Activity review report, pocket gopher-reforestation activity review: West. Reg. 4 and 6. Washington, DC: U.S. Department of Agriculture; 1979. 26 p.

U.S. Department of Agriculture, Forest Service. Animal damage control handbook. FSH 1609.22 R6. Portland, OR: U.S. Department of Agriculture, Forest Service, Region 6; 1968. 226 p.

U.S. Department of the Interior, Fish and Wildlife Service. Pocket gopher control. Wildl. Leaflet 340. Washington, DC: U.S. Department of the Interior, Fish and Wildlife Service; 1952. 6 p.

U.S. Department of the Interior, Fish and Wildlife Service. Pocket gophers and their control in Oregon. Forest Series, Animal Damage Control Leaflets. Portland, OR: U.S. Department of the Interior, Fish and Wildlife Service, Division of Wildlife Service; 1952. 2 p.

Van Gorder, C. L. Champion gopher catchers. Co. Agent & Vo-Ag Teacher. 16(5): 20-29; 1960.

Villa-Ramirez, B. Las Tuzas (control of pocket gophers as field pests). Tierra Mexico. 8: 546-549; 1953.

Ward, A. L.; Hansen, R. M. The burrow-builder and its use for control of pocket gophers. Spec. Sci. Rep., Wildl. No. 47. Washington, DC: U.S. Department of the Interior, Fish and Wildlife Service; 1960. 7 p.

Ward, A. L.; Hansen, R. M. Pocket gopher control with the burrow-builder in forest nurseries and plantations. J. For. 60(1): 42-44; 1962.

Ward, A. L.; Hegdal, P. L.; Richens, V. B.; Tietjen, H. P. Gophacide, a new pocket gopher control agent. J. Wildl. Manage. 31(2): 332-338; 1967.

Washburn, F. L.; Mickel, C. E. Effectiveness of calcium cyanide in poisoning the pocket gopher, *Geomys bursarius* (Shaw). Tech. Bull. 27. St. Paul, MN: Minnesota Agricultural Experiment Station; 1925. 14 p.

Washington State University. Pocket gopher control. Exten. Mimeo E. M. 3799. Pullman, WA: Washington State University; 1973. 17 p.

Washington State University. Pocket gopher control. Exten. Mimeo E. M. 1365. Pullman, WA: Washington State University; 1952. 10 p.

Webster, M. H. Controlling damage by deer, rabbits, porcupine and gophers in orchards. In: Proceedings, 1954 Washington State Horticultural Association: 50th annual meeting; 1954 December 6-8; Yakima, WA. Pullman, WA: Washington State Horticultural Association; 1954: 28-31.

Welch, J. F. A review of chemical repellents for rodents. J. Agric. Food Chem. 2(3): 142-149; 1954.

Wick, W. Q.; Landforce, A. S. Mole and gopher control. Ext. Bull. 804. Corvallis, OR: Oregon State University; 1965. 16 p.

Wight, H. M. The life history and control of the pocket gopher in the Willamette Valley. Bull. 153. Corvallis, OR: Oregon Agriculture Experiment Station; 1918. 55 p.

Williston, H. L. Control of animal damage to young plantations in the south. J. For. 72(2): 78-81; 1974.

Wolleb, E. Fumigating squirrels and gophers. Pacific Rural Press. 21: 180; 1881.

Worswick, J. D. Gopher control important. Calif. Cultivator. 92: 244-245; 1947.

Population Estimation (PE)

Artmann, J. W. Telemetric study of the pocket gopher, *Geomys bursarius*. St. Paul, MN: University of Minnesota; 1967. 81 p. Thesis.

Beck, R. F.; Hansen, R. M. Estimating plains pocket gopher abundance on adjacent soil types by a visual technique. J. Range Manage. 19(4): 224-225; 1966.

Driscoll, R. S.; Watson, T. C. Aerial photography for pocket gopher populations. In: Proceedings, 1974 symposium on remote sensing and photo interpretation; 1974 October; Banff, AL. Ottawa, ON: Canadian Institute of Surveying; 1974: 481-492.

Ingles, L. G.; Clothier, R.; Crawford, L. A. Methods of estimating pocket gopher populations. J. Wildl. Manage. 13(3): 311-312; 1949.

Julander, O.; Ferguson, R. B.; Dealy, J. E. Measure of animal range use by signs. Misc. Publ. 940. Washington, DC: U.S. Department of Agriculture; 1963. 172 p.

Mohr, C. O.; Stumpf, W. A. Comparison of methods for calculating areas of animal activity. J. Wildl. Manage. 30(2): 293-304; 1966.

Reid, V. H.; Hansen, R. M.; Ward, A. L. Counting mounds and earth plugs to census mountain pocket gophers. J. Wildl. Manage. 39(2): 327-334; 1966.

Capture, Housing, and Handling (CHH)

Baker, R. J.; Williams, S. L. A live trap for pocket gophers. J. Wildl. Manage. 36(4): 1320-1322; 1972.

Handley, G. H. Housing of the pocket gopher in captivity. J. Mammal. 25: 407-408; 1944.

Howard, W. E. A live trap for pocket gophers. J. Mammal. 33(1): 61-65; 1952.

Ingles, L. G. An improved live trap for pocket gophers. Murrelet. 30(3): 55-56; 1949.

Johnson, C. E. Notes on a pocket gopher in captivity. J. Mammal. 7(1): 35-37; 1926.

Keith, J. O. An efficient and economical pocket gopher enclosure. J. Range Manage. 14(6): 332-334; 1961.

Sargent, A. B. A live trap for pocket gophers. J. Mammal. 47(4): 729-731; 1966.

Scheffer, T. H. Hints on live trapping. J. Mammal. 15(3): 197-202; 1934.

Sherman, H. B. A box trap for the capture of live *Geomys*. J. Mammal. 22(2): 182-184; 1941.

Sherman, H. B.; Barrington, B. A. A pocket gopher cage. J. Mammal. 22: 91-93; 1941.

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A state-of-the-knowledge report on available information on gopher biology, ecology, damage, and control. Habits and related problems are reviewed for gopher species throughout the United States, but attention is focused on pocket gophers in northwestern forest enviroments. A bibliography containing over 1,000 literature citations is included.

KEYWORDS: pocket gopher, forest plantation protection, plastic seedling protectors, poison bait, burrow builder, tree damage

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A Computer System for Testing Fire Management Prescriptions:

Part 1—User's Manual

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RESEARCH SUMMARY

This report describes a user-oriented computer system that allows fire managers to examine computerized historical fire occurrence and weather records, and to thus identify ignitions that would meet criteria for prescribed fires. Qualifying fires are "allowed to burn" under prevailing weather conditions until extinguished by precipitation or until prescribed conditions are exceeded. Test prescription parameters may include up to 60 fire-occurrence, fire-weather, fire-danger, and fire-manning level variables.

The report includes step-by-step instructions and samples of input and output. Part 2—Computer Terminal Operator's Manual (Bevins and Fischer 1983) is available as a separate general technical report.

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A Computer System for Testing Fire Management Prescriptions:
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INTRODUCTION

Federal land managers increasingly formulate and evaluate a range of options before deciding on a specific fire management strategy for a given wildland area. This task is most often associated with integrated land management planning. The range of fire management options formulated usually corresponds to a range of land management alternatives.

Evaluation criteria applied to different fire management options usually include goals for number of fires and acres burned, both for wildfires and for prescribed fires. FOCUS, a large-scale computer simulation model, provides, among other things, information useful for evaluating how well various fire management strategies meet established wildfire goals (Bratten and others 1981; Greenlee 1982). Program PRESCRIBE (Furman 1979) and programs RXWTHR and RXBURN (Bradshaw and Fischer 1981a, 1981b) are computer programs that aid formulation and evaluation of alternative prescriptions for traditional prescribed fire (manager-ignited or "scheduled" prescribed fires). Information provided by these programs is useful in determining the probability of achieving scheduled prescribed fire goals.

Johnson and Main (1978) have also developed a computer program RXBURN to aid in planning prescribed fire. Although its output is similar to some of the output from the PRESCRIBE and RXWTHR and RXBURN programs cited above, it is not on-line at the Fort Collins Computer Center.

The computer system described in this report is also designed to provide information that can be used to assess how well various fire management strategies, or prescriptions, meet prescribed fire goals. Of particular concern here are those fire management prescriptions that allow natural or accidental ignitions to burn under planned conditions to accomplish land management objectives. Such fires are variously labeled natural fires, management fires, and unplanned prescribed fires. We will refer to them as being unscheduled prescribed fires because although their occurrence is planned (anticipated, expected) the timing of their occurrence is unknown, hence unscheduled.

Programs RXBUILD and RXFIRES evaluate alternative prescriptions for unscheduled prescribed fires within specific fire management planning areas. The programs examine computerized historical fire occurrence and weather records, and from these records identify ignitions that would have qualified as prescribed fires according to the conditions of the test prescription. Qualifying fires are "allowed to burn" under prevailing weather conditions until extinguished by precipitation or until they burn out of prescription. In actual practice, a fire that burns out of prescription is declared an escaped fire. Subsequent action is based on results of an escaped fire analysis (Nelson 1979). The decision may be to suppress the fire or to allow it to burn, or some modification of either of these actions. Test prescription parameters may include up to 60 fire-occurrence, fire-weather, fire-danger-rating, and fire-manning-level variables.

SYSTEM DESCRIPTION

Two interrelated computer programs, RXBUILD and RXFIRES, make up the system. The system is designed to use fire report information stored in the National Fire Occurrence Data Library (NFODL) (Yancik and Roussopoulos 1982) and the climatological data stored in the National Fire Weather Data Library (NFWDL) (Furman and Brink 1975). Both data libraries are located at the USDA Forest Service's Fort Collins, Colo., Computer Center (FCCC). Programs RXBUILD and RXFIRES are written in ASCII 3.9X-77 FORTRAN and are stored in the Northern Region shared library CSSG*R1LIB at FCCC. The programs are available via either remote terminal or batch processing to all who have access to FCCC facilities.

Program RXBUILD

Program RXBUILD collates the necessary fire occurrence and fire weather data from computer archives and creates a data set specific to a fire management area described by the user. The data set may be printed at the user's request.

FEATURES OF RXBUILD

RXBUILD obtains fire reports specific to a user-designated set of up to 10 National Forest Ranger Districts. Reports may be obtained for any set of fire years available from the National Fire Occurrence Data Library.

Fire reports are accessed from a file created by the NFODL routine NFODL*PROGRAMS.RETRIEVE. The user does not have to prepare fire report forms as program input.

The user may specify any AFFIRMS (Helfman and others 1980) weather station, fuel model, slope class, herbaceous type, climate class, etc., to obtain fire weather observations for each District. Districts may share the same AFFIRMS station or use separate stations. All fires within the District will use the designated AFFIRMS station weather data to test prescriptions in program RXFIRES.

RXBUILD automatically retrieves fire weather data directly from the National Fire Weather Data Library for the selected AFFIRMS stations. The user does not have to prepare, access, or store the weather data as a separate step. RXBUILD automatically processes each station's fire weather observations through the NFDR78*FIREFAMILY.FIRDAT1 (Main, Staub, and Paananen 1982) routines to obtain daily National Fire Danger Rating System (NFDRS) (Deeming and others 1977) indices. NFDRS indices may thereafter be used as prescription parameters in program RXFIRES.

RXBUILD will compute up to three manning variables for each daily AFFIRMS observation. Manning variables may be based upon any user-designated weather observation or danger rating. Classes within the manning variables are defined by 90th and 97th percentile values as described by Helfman and others (1980).

RXBUILD constructs a sequential-access fire report file and a direct-access fire weather, danger, and manning file for the specified set of Ranger Districts, AFFIRMS stations, and years. RXBUILD will print the fire report and fire weather files if requested.

LIMITATIONS OF PROGRAM RXBUILD

Programs RXBUILD and RXFIRES use archival data from the National Fire Weather Data Library. Gibson (1977), Bradshaw and Fischer (1981a), and others have noted limitations on the use of NFWDL records for planning prescribed fires; observations are taken only once per day at typically severe sites over the length of the fire season. As a result, the single observation must be considered representative of the entire day when in fact it represents conditions at midafternoon on exposed southern aspects. Second, weather observations are rarely recorded for more than 5 months each year. Data are therefore scarce for the pre- and postfire seasons, periods of special interest when determining fire prescriptions.

Program RXBUILD will construct fire report and fire weather files for a maximum of 10 Ranger Districts on a single National Forest. If the fire management area covers more than 10 Districts, or includes Districts from more than one Forest, separate RXBUILD runs can be made to create two or more sets of fire report and weather files. Program RXFIRES is then run once for each set of files and the results combined.

Program RXFIRES

Program RXFIRES reads the user's test prescription and checks each historical fire for compliance. A table of qualifying unscheduled prescribed fires and nonqualifying wildfires by year and size class is printed. The user may also request a case history of each unscheduled prescribed fire and a fire load summary table. RXFIRES may be used repeatedly to test alternative prescriptions for a single fire management area data set created by RXBUILD.

FEATURES OF PROGRAM RXFIRES

The user of program RXFIRES may restrict test prescription analysis to any subset of fire reports on file. This is accomplished by specifying "exclusion criteria" based on any fire variable. The analysis may be restricted, for example, to fires from selected Districts, watersheds, ignition sources, elevation bands, cover types, seasonal dates, and so on. Up to 99 exclusion criteria may be specified.

The user may specify up to 99 "suppression criteria" based upon the value of any fire-occurrence, fire-weather, NFDRS-index, or manning-level variable. The suppression criteria therefore determine the unscheduled prescribed fire test prescription.

The user may elect to "preview" any fire-weather, NFDRS-index, or manning-level suppression criterion for any number of days preceding each fire. This permits the use of a suppression criterion such as "suppress the fire if the energy release component is greater than 50 **on any of the 4 days preceding a fire.**"

Historical fires that are not excluded from the analysis are tested against the suppression criteria. If none of the suppression criteria are met, the fire is declared an "unscheduled prescribed fire" and is monitored every day thereafter until one of the following conditions occurs:

1. One of the fire-weather or NFDRS-index suppression criteria is met and the fire becomes a "wildfire";
2. The fire is extinguished by an excessive amount of precipitation in a 24-hour period (an amount defined by the user);
3. The fire's AFFIRMS station is closed for 20 consecutive days indicating the end of the season's weather observations.

RXFIRES prints a yearly summary by size class of:

1. Total fire reports on the fire report file;
2. Total fire reports not excluded from the analysis;
3. Total wildfires;
4. Total unscheduled prescribed fires; and
5. Total unscheduled prescribed fires that later met a suppression criteria.

RXFIRES will additionally print a short case history of each unscheduled prescribed fire (output level 2). Each case history includes:

1. General fire description (Forest Supervisor's number, cause, date, Forest, District, and legal description);
2. Up to 12 additional variables selected by the user; and

3. The day the fire was extinguished by precipitation, burned into the end of the season, or escaped prescription. In the latter case, the suppression criteria that was met and its value is printed.

RXFIRES will additionally print a wildfire vs. unscheduled prescribed fire load summary (output level 3). Up to 15 years of fire reports can be processed in a single RXFIRES run.

LIMITATIONS OF PROGRAM RXFIRES

RXFIRES is **not** a fire model. It cannot predict prescribed fire spread rate, perimeter, or acres burned. It cannot determine if, nor when, fires burn across management area boundaries, final size and perimeter of unsuppressed fires, nor final fire size, perimeter, nor hours to control if suppressed. The following restrictions therefore exist when interpreting RXFIRES output:

1. Once an ignition is determined to be an unscheduled prescribed fire, its **daily weather-observation, NFDRS-index, and manning-level** prescription variables are monitored for compliance. **Fire-occurrence** variables used as suppression criteria cannot be monitored in this fashion as their values do not change from day to day on the 5100-29 fire report forms. Thus, RXFIRES cannot determine when or if a fire burns outside a management area, across an elevational contour, into the next watershed or District, etc.
2. Because it is not a fire model, users must apply their own judgment on the potential of each fire to escape the management area. The RXBUILD fire report and fire weather file listings may be useful in simulating the potential behavior of prescribed fires.
3. The final size class of unscheduled prescribed fires listed in the yearly summary table is the same as recorded on the 5100-29 forms. No attempt is made to determine a historical fire's final size class had it not been suppressed.
4. Once an unscheduled prescribed fire meets any of the suppression criteria, it is again considered to be a wildfire (even though in actual practice the fire may be allowed to burn on as a result of management decision based on an escaped fire analysis). The number of days it burned as a prescribed fire is added to the daily prescribed fire load calculations. The number of days it then burned as a wildfire, however, is determined solely from its 5100-29 "hours to control" entry, although the fire may have substantially increased in size and control difficulty. The daily fire load summary table may therefore seriously underestimate the drain of these fires on fire management resources. Again, some compensation may be made by consulting the report listing for these fires and making judgments on difficulty to control and final size under the existing conditions.

SYSTEM OPERATION

The steps necessary to successfully operate programs RXBUILD and RXFIRES are listed in table 1. The left-hand column in table 1 identifies the steps usually performed by the fire management officer, fire planner, or other end-user of the program output. This person is primarily concerned with selecting appropriate program inputs and interpreting program outputs. This report provides instructions to these users.

The right-hand column in table 1 identifies the steps usually performed by a computer terminal operator or computer specialist who enters the data, submits the programs for execution, and maintains the data files. A companion report, "Part 2—Computer Terminal Operator's Manual" (Bevins and Fischer 1983) contains detailed instructions for those steps. Variables that can be used as prescription parameters in RXBUILD and RXFIRES are listed in table 2.

Table 1.—List of steps necessary to operate programs RXBUILD and RXFIRES

Fire planner responsibilities	Terminal operator responsibilities
PROGRAM RXBUILD	
1. Complete RXBUILD input worksheet.	
	2. Determine NFWDL tape name. (Consult Furman and Brink 1975).
	3. Create NFODL SPSS-style fire file. (Consult Yancik and Roussopoulas 1982).
	4. Access CSSG*R1LIB.RXBUILD to enter worksheet items and create an input directive file.
	5. @ADD the RXBUILD directive file to execute CSSG*R1LIB.RXBUILD2.
6. Interpret RXBUILD output.	
PROGRAM RXFIRES	
7. Complete RXFIRES input worksheet.	
	8. Access CSSG*R1LIB.RXFIRES to enter worksheet items and create an input directive file.
	9. @ADD the RXFIRES directive file to execute CSSG*R1LIB.RXFIRES2.
10. Interpret RXFIRES output.	
11. Return to Step 7 for next test prescription.	

Table 2.—List of variables that can be used as prescription parameters; programs RXBUILD and RXFIRES

Variable code	Variable name	Variable value code and unit of measure
1	Agency	1 = USDA Forest Service
2	Region	1=R1, 2=R2, ..., 0=R10
3	Administering National Forest	Coded; consult FSH 5109-14[1]
4	District	Coded; consult FSH 5109-14
5	Reporting National Forest	Coded; consult FSH 5109-14
6	Jurisdiction at origin	Coded; consult FSH 5109-14
7	State	Coded; consult FSH 5109-14
8	County	Coded; consult FSH 5109-14
9	Watershed	Coded; consult FSH 5109-14
10	Supervisor's fire number	
11	Year of origin	70=1970, 81=1981
12	Month of origin	1=Jan, 2=Feb, ..., 12=Dec

(con.)

Table 2. (con.)

Variable code	Variable name	Variable value code and unit of measure
13	Date of origin	0101 = Jan 1, 0615 = Jun 15, 1231 = Dec 31
14	Day of week of origin	1 = Sun, 2 = Mon, ..., 7 = Sat
15	Statistical cause	Coded; consult FSH 5109-14
16	General cause	Coded; consult FSH 5109-14
17	Specific cause	Coded; consult FSH 5109-14
18	Fire size class	1 = A, 2 = B, ..., 7 = G
19	Acres burned	Actual value; nearest whole acre
20	People who started fire	Coded; consult FSH 5109-14
21	Hour of fire origin	Nearest hour, 24-hour clock
22	Total hours to control	Actual value; nearest whole hour
23	Max. suppression personnel	Actual number
24	Slope class	Coded; consult FSH 5109.14
25	Aspect class	Coded; consult FSH 5109.14
26	Elevation class	Coded; consult FSH 5109.14
27	Topography class	Coded; consult FSH 5109.14
28	Cover type at origin	Coded; consult FSH 5109.14
29	Fuel type at origin	Coded; consult FSH 5109.14
30	Fuel type prevailing	Coded; consult FSH 5109.14
31	State of the weather	Coded; consult FSH 5109.14
32	Temperature	Actual value; nearest whole °F
33	Relative humidity	Actual value; nearest whole percent
34	Wind direction	Coded; consult Deeming and others (1977)
35	Wind speed	Actual value; nearest whole mile per hour
36	Maximum temperature	Actual value; nearest whole °F
37	Minimum temperature	Actual value; nearest whole °F
38	Maximum relative humidity	Actual value; nearest whole percent
39	Minimum relative humidity	Actual value; nearest whole percent
40	Precipitation duration	Actual value; nearest whole hour
41	Precipitation trace	1 = trace, 0=none
42	Precipitation amount	Actual value; nearest hundreth of an inch
43	Lightning activity level	Coded
44	Man-caused risk	Actual value; nearest hundreth
45	1-hour fuel moisture	Actual value; nearest tenth percent
46	10-hour fuel moisture	Actual value; nearest tenth percent
47	100-hour fuel moisture	Actual value; nearest tenth percent
48	1000-hour fuel moisture	Actual value; nearest tenth percent
49	Live woody fuel moisture	Actual value; nearest whole percent
50	Live herbaceous fuel moisture	Actual value; nearest whole percent
51	Ignition component	Actual value
52	Spread component	Actual value
53	Energy release component	Actual value
54	Person-caused occurrence index	Actual value
55	Lightning occurrence index	Actual value
56	Burning index	Actual value
57	Fire load index	Actual value
58	Manning level variable 1	Coded; user defined
59	Manning level variable 2	Coded; user defined
60	Manning level variable 3	Coded; user defined

---

[1] USDA Forest Service, Individual Fire Report Handbook, Form 5100-29.

Program RXBUILD

The input requirements of program RXBUILD include all the parameters to (1) select Districts and years of fire reports from the NFODL, (2) to select AFFIRMS stations and years of weather observations from the NFWDL, (3) to derive NFDRS indices using the FIREFAMILY.FIRDAT1 processor, and (4) to define manning class variables.

RXBUILD INPUT WORKSHEET

The five RXBUILD worksheets facilitate the organization and proper entry of the variety of inputs required. All worksheet input items have a reference number corresponding to the following instructions. Worksheets suitable for reproduction are included in appendix A.

Use of the input worksheets is essential for two reasons. First, it ensures that all the necessary inputs have been properly considered and entered onto the form before accessing the computer. Second, the worksheets are the source documents from which data are entered onto a DEMAND terminal. Program RXBUILD prompts the terminal operator for inputs using worksheet facsimiles.

Examples of properly completed RXBUILD input worksheets are included with the instructions that follow. These examples demonstrate all program RXBUILD options. In the examples, data files for the Cabinet Wilderness Fire Management Area, Kootenai National Forest, are requested. The fire management area includes portions of the Cabinet, Libby, and Troy Ranger Districts. Unlike Libby and Troy, the Cabinet District does not have a long AFFIRMS weather record and must, consequently, use data from the Libby weather station.

INSTRUCTIONS FOR COMPLETING RXBUILD INPUT WORKSHEETS

There is one overriding rule for input entry:

ALL NUMERIC ENTRIES MUST INCLUDE A DECIMAL POINT!

In the case of whole numbers, the decimal point must be appended. For example, the number "twelve" must be entered as "12.".

The five separate input worksheets must be organized in the following manner for entry on a computer terminal:

Sheet No. 1 - Run Identification (required)
Sheet No. 2 - AFFIRMS Station No. 1 Parameters (required)
    Sheet No. 3 - Manning Variables for AFFIRMS Station No. 1 (optional)
    Sheet No. 2 - AFFIRMS Station No. 2 Parameters (optional)
    Sheet No. 3 - Manning Variables for AFFIRMS Station No. 2 (optional)

.
etc.
.

    Sheet No. 2 - AFFIRMS Station No. 10 Parameters (optional)
    Sheet No. 3 - Manning Variables for AFFIRMS Station No. 10 (optional)
Sheet No. 4 - Date Parameters (required)
Sheet No. 5 - District No. 1 Parameters (required)
    Sheet No. 5 - District No. 2 Parameters (optional)

.
etc.
.

    Sheet No. 5 - District No. 10 Parameters (optional)

Sheet No. 1—Run Identification

One sheet No. 1 is completed for each RXBUILD run. Item numbers below correspond to item numbers on RXBUILD input worksheet No. 1 (see exhibit 1a for example).

1. TITLE.
   Enter any information identifying the fire management area. You may use up to 80 letters, numbers, or special characters.
2. USER NAME.
   Enter your name or any other identifying information. You may use up to 80 letters, numbers, or special characters.
3. REGION NAME OR NUMBER.
   Enter the Region name, number, or any other identifying information. You may use up to 80 letters, numbers, or special characters.
4. FOREST NAME.
   Enter the Forest name or any other identifying information. You may use up to 80 letters, numbers, or special characters.
5. FOREST ADP CODE.
   Enter the 1- or 2-digit Forest ADP code used on the 5100-29 individual fire reports. (Remember the decimal point.) Refer to the Regional supplement to FSH 5109.14, Individual Fire Report Handbook for appropriate Forest codes.
6. NUMBER OF AFFIRMS WEATHER STATIONS.
   Enter the number of individual AFFIRMS stations to be used. (Remember the decimal point.) In the example in exhibit 1a, only two stations are requested for the three Districts because the Cabinet District shares the Libby District's AFFIRMS station.
   List the AFFIRMS stations to be used (2 in the example) by name and number in the spaces provided. List in order of increasing station number; the smallest number first, the largest last. Now complete the sequence number (6..) at the left for the stations listed. Add a "1" (6.1.) for the first station in the list, a "2" (6.2.) for the second, and so forth. This is for documentation and for aiding proper entry on work sheets No. 2 and No. 3.

Date 3-82

RXBUILD INPUT WORKSHEET

SHEET NO. 1 -- RUN IDENTIFICATION

1. TITLE. (Enter 1 to 80 characters.)

CABINET WILDERNESS FIRE MANAGEMENT PLAN

2. USER NAME. (Enter 1 to 80 characters.)

COLLIN D. BEVINS

3. REGION NAME OR NUMBER. (Enter 1 to 80 characters.)

NORTHERN REGION

4. FOREST NAME. (Enter 1 to 80 characters.)

KOOTENAI N.F

5. FOREST ADP CODE. 14.

6. NUMBER OF AFFIRMS WEATHER STATIONS TO BE USED IN THIS RUN.[1/] 2.

List of AFFIRMS stations to be used. List in order of increasing station number - smallest number first, largest number last.

6.1.	TROY	240112
6.2.	BIG SWEDE	240116
6.__.		
6.__.		
6.__.		
6.__.		

[1/] Complete a separate Sheet No. 2 for each of the AFFIRMS stations listed in Item No. 6 above.

Page 1 of 7

Exhibit 1a.—Sample RXBUILD Input Worksheet No. 1, Run Identification.

Sheet No. 2—AFFIRMS Station Parameters

A separate sheet No. 2 must be completed for **each** AFFIRMS station declared in item 6, sheet No. 1. These sheets must be arranged in order of increasing AFFIRMS station 6-digit ID (smallest ID number first, largest ID number last). Data entries are usually the same as for daily AFFIRMS reporting (see exhibits 1b and 1d for samples).

6.____. 6-DIGIT AFFIRMS STATION ID.
Enter the 6-digit station ID as in daily AFFIRMS reporting. Remember to add the trailing decimal point.

6.____.1 AFFIRMS STATION NAME.
Enter the station name as in daily AFFIRMS reporting or FIREFAMILY.FIRDAT1 input. You may use up to 20 letters, numbers, or special characters.

6.____.2 AFFIRMS STATION ELEVATION.
Enter the station elevation (0. through 12000. feet) as in daily AFFIRMS reporting or FIREFAMILY.FIRDAT1 input. Remember to add the trailing decimal point.

6.____.3 AFFIRMS STATION LATITUDE.
Enter the station latitude to the nearest whole degree as in daily AFFIRMS reporting or FIREFAMILY.FIRDAT1 input. Remember to add the trailing decimal point.

6.____.4 NFDRS FUEL MODEL.
Enter the NFDRS fuel model letter (A through U, except M) as described by Deeming and others (1977). Select the same fuel model used in daily AFFIRMS reporting or FIREFAMILY.FIRDAT1 input, or one that more accurately describes the fire management area.

6.____.5 NFDRS SLOPE CLASS.
Enter the NFDRS slope class (1. through 5.) as described by Deeming and others (1977). Remember to add the trailing decimal point. Select the slope class used in daily AFFIRMS reporting or FIREFAMILY.FIRDAT1 input, or one that more accurately describes the fire management area.

6.____.6 NFDRS HERBACEOUS TYPE.
Enter the NFDRS herbaceous type ("P" for perennial or "A" for annual) as described by Deeming and others (1977). Select the letter used in daily AFFIRMS reporting or FIREFAMILY.FIRDAT1 input.

6.____.7 NFDRS CLIMATE CLASS.
Enter the NFDRS climate class (1. through 4.) as described by Deeming and others (1977). Select the climate class used in daily AFFIRMS reporting or FIREFAMILY.FIRDAT1 input. Remember to add the decimal point.

6.____.8 NFDRS GREENUP DATE.
Enter the month and day of yearly greenup. Use two digits for the month and two digits for the day. For example, May 15 would be entered as "0515." and June 1 would be entered as "0601.". Note that the decimal point is added. Select the greenup date used in daily AFFIRMS reporting or FIREFAMILY.FIRDAT1 input.

6.____.9 NFDRS FIRST FREEZE DATE.
Enter the month and day of the first annual freeze. Use two digits for the month and two digits for the day. For example, September 15 would be entered as "0915." and October 1 would be entered as "1001.". Note that the decimal point is added. Select the first freeze date used in daily AFFIRMS reporting or FIREFAMILY.FIRDAT1 input.

6.____.10 NFDRS WEEKDAY MAN RISK FACTOR.
Enter the NFDRS weekday man risk factor (0. through 100.) as described by Deeming and others (1977). Select the value used in daily AFFIRMS reporting or FIREFAMILY.FIRDAT1 input. Remember the decimal point.

6.____.11 NFDRS WEEKEND MAN RISK FACTOR.
Enter the NFDRS weekend man risk factor (0. through 100.) as described by Deeming and others (1977). Select the value used in daily AFFIRMS reporting or FIREFAMILY.FIRDAT1 input. Remember the decimal point.

6.____.12 NFDRS LIGHTNING SCALING FACTOR.
Enter the NFDRS lightning scaling factor (0. through 100.) as described by Deeming and others (1977). Select the value used in daily AFFIRMS reporting or FIREFAMILY.FIRDAT1 input. Remember the decimal point.

6.____.13 NUMBER OF MANNING VARIABLES.
Enter the number of manning variables (0. to 3.) to be derived from AFFIRMS station weather observations or NFDRS indices. Use this option if manning level is a potential test parameter for unscheduled prescribed fires. Remember to add the decimal point.

Date 3-82

RXBUILD INPUT WORKSHEET

SHEET NO. 2 -- AFFIRMS STATION PARAMETERS

6.1. 6-DIGIT AFFIRMS STATION ID. 240112.

6.1.1 AFFIRMS STATION NAME.[1/] TROY RD AFFIRMS

6.1.2 AFFIRMS STATION ELEVATION. 1950.

6.1.3 AFFIRMS STATION LATITUDE. 48.

6.1.4 NFDRS FUEL MODEL. G

6.1.5 NFDRS SLOPE CLASS. 3.

6.1.6 NFDRS HERBACEOUS TYPE. P

6.1.7 NFDRS CLIMATE CLASS. 3.

6.1.8 NFDRS GREENUP DATE. 601.

6.1.9 NFDRS FIRST FREEZE DATE. 915.

6.1.10 NFDRS WEEKDAY MAN RISK FACTOR. 1.

6.1.11 NFDRS WEEKEND MAN RISK FACTOR. 1.

6.1.12 NFDRS LIGHTNING SCALING FACTOR. 1.

6.1.13 NUMBER OF MANNING VARIABLES.[2/] 2.

[1/] 20 characters maximum.

[2/] Complete Sheet No. 3 if Item No. 6.__.13 is greater than 0. A separate Sheet No. 3 must be completed for each AFFIRMS station indicated in Item 6, Sheet No. 1.

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Exhibit 1b.—Sample RXBUILD Input Worksheet No. 2, AFFIRMS Station Parameters, for first AFFIRMS station to be used in this run (AFFIRMS station with smallest ID number).

Sheet No. 3—Manning Variable Parameters

Sheet No. 3 must be completed for **each** AFFIRMS station for which manning variables are to be derived (see exhibits 1c and 1e for samples). If no manning variables are requested, sheet No. 3 is not used. **The completed sheet must be appended to its corresponding AFFIRMS station sheet No. 2** (see exhibits 1b and 1d for samples).

6.____.13.____.1 BASE VARIABLE FOR MANNING LEVEL.

Enter the 2-digit code (31. through 57.) of the variable from which manning level is derived (table 2). Select any of the weather observation variables (31. through 50.) or NFDRS indices (51. through 57.). Select the variable used in daily AFFIRMS reporting. Remember the decimal point.

6.____.13.____.2 NO. OF MANNING LEVEL CLASSES.

Enter the number of classes (4. through 10.) to be defined and add the decimal point. Select the same number used in daily AFFIRMS reporting. RXBUILD will establish class boundaries as per Helfman and others (1980). Class 1 is always reserved for zero values. The remaining classes will be the same as those in AFFIRMS output.

6.____.13.____.3 90th PERCENTILE VALUE OF BASE VARIABLE.

Enter the 90th percentile value of the base variable used in daily AFFIRMS reporting or from FIREFAMILY.FIRDAT1 output. Remember to add the decimal point.

6.____.13.____.4 97th PERCENTILE VALUE OF BASE VARIABLE.

Enter the 97th percentile value of the base variable used in daily AFFIRMS reporting or from FIREFAMILY.FIRDAT1 output. Remember to add the decimal point.

In the example (exhibit 1c), two manning variables are defined. The first manning variable is computed from the NFDRS Energy Release Component (variable 53, table 2). The second manning variable is derived from the NFDRS Burning Index (variable 56, table 2).

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RXBUILD INPUT WORKSHEET

SHEET NO. 3 -- RUN IDENTIFICATION

AFFIRMS STATION NO. 2 4 0 1 1 2

MANNING VARIABLE NO. 1

6.1.13.1.1	BASE VARIABLE FOR MANNING LEVEL.	53.
6.1.13.1.2	NO. OF MANNING LEVEL CLASSES.	5.
6.1.13.1.3	90th PERCENTILE VALUE OF BASE VARIABLE.	62.
6.1.13.1.4	97th PERCENTILE VALUE OF BASE VARIABLE.	69.

MANNING VARIABLE NO. 2

6.1.13.2.1	BASE VARIABLE FOR MANNING LEVEL.	56.
6.1.13.2.2	NO. OF MANNING LEVEL CLASSES.	5.
6.1.13.2.3	90th PERCENTILE VALUE OF BASE VARIABLE.	59.
6.1.13.2.4	97th PERCENTILE VALUE OF BASE VARIABLE.	68.

MANNING VARIABLE NO. 3

6.__.13.3.1	BASE VARIABLE FOR MANNING LEVEL.	__ __ __
6.__.13.3.2	NO. OF MANNING LEVEL CLASSES.	__ __ __
6.__.13.3.3	90th PERCENTILE VALUE OF BASE VARIABLE.	__ __ __ __
6.__.13.3.4	97th PERCENTILE VALUE OF BASE VARIABLE.	__ __ __ __

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Exhibit 1c.—Sample RXBUILD Input Worksheet No. 3, Manning Variable Parameters, for first AFFIRMS station to be used in this run (AFFIRMS station with smallest ID number).

Date 3-82

RXBUILD INPUT WORKSHEET

SHEET NO. 2 -- AFFIRMS STATION PARAMETERS

6.2.	6-DIGIT AFFIRMS STATION ID.	240116.
6.2.1	AFFIRMS STATION NAME.[1/]	BIG SWEDE MTN
6.2.2	AFFIRMS STATION ELEVATION.	4336.
6.2.3	AFFIRMS STATION LATITUDE.	48.
6.2.4	NFDRS FUEL MODEL.	G
6.2.5	NFDRS SLOPE CLASS.	3.
6.2.6	NFDRS HERBACEOUS TYPE.	P
6.2.7	NFDRS CLIMATE CLASS.	3.
6.2.8	NFDRS GREENUP DATE.	601.
6.2.9	NFDRS FIRST FREEZE DATE.	915.
6.2.10	NFDRS WEEKDAY MAN RISK FACTOR.	1.
6.2.11	NFDRS WEEKEND MAN RISK FACTOR.	1.
6.2.12	NFDRS LIGHTNING SCALING FACTOR.	1.
6.2.13	NUMBER OF MANNING VARIABLES.[2/]	2.

[1/] 20 characters maximum.

[2/] Complete Sheet No. 3 if Item No. 6.__.13 is greater than 0. A separate Sheet No. 3 must be completed for each AFFIRMS station indicated in Item 6, Sheet No. 1.

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Exhibit 1d.—Sample RXBUILD Input Worksheet No. 2, AFFIRMS Station Parameters, for second AFFIRMS station to be used in this run (AFFIRMS station with largest ID number).

Date 3-82

RXBUILD INPUT WORKSHEET

SHEET NO. 3 -- RUN IDENTIFICATION

AFFIRMS STATION NO. 2 4 0 1 1 6

MANNING VARIABLE NO. 1

6.2.13.1.1	BASE VARIABLE FOR MANNING LEVEL.	53.
6.2.13.1.2	NO. OF MANNING LEVEL CLASSES.	5.
6.2.13.1.3	90th PERCENTILE VALUE OF BASE VARIABLE.	62.
6.2.13.1.4	97th PERCENTILE VALUE OF BASE VARIABLE.	69.

MANNING VARIABLE NO. 2

6.2.13.2.1	BASE VARIABLE FOR MANNING LEVEL.	56.
6.2.13.2.2	NO. OF MANNING LEVEL CLASSES.	5.
6.2.13.2.3	90th PERCENTILE VALUE OF BASE VARIABLE.	59.
6.2.13.2.4	97th PERCENTILE VALUE OF BASE VARIABLE.	68.

MANNING VARIABLE NO. 3

6.__.13.3.1	BASE VARIABLE FOR MANNING LEVEL.	___ ___ ___
6.__.13.3.2	NO. OF MANNING LEVEL CLASSES.	___ ___ ___
6.__.13.3.3	90th PERCENTILE VALUE OF BASE VARIABLE.	___ ___ ___ ___
6.__.13.3.4	97th PERCENTILE VALUE OF BASE VARIABLE.	___ ___ ___ ___

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Exhibit 1e.—Sample RXBUILD Input Worksheet No. 3, Manning Variable Parameters, for second AFFIRMS station to be used in this run (AFFIRMS station with largest ID number).

Sheet No. 4—Date Parameters

One sheet No. 4 must be completed for every RXBUILD run. It must follow the last sheet No. 3 (if used) defining manning variables for the last AFFIRMS station (see exhibit 1f for sample).

7. BEGINNING YEAR.
   Enter the first year of fire reports and weather data to be processed. Enter only the last two digits of the year and add the decimal point. For example, enter 1970 as "70.". Fire reports and weather observations preceding this year will not be processed. Consult the NFODL and NFWDL for the years of data available for specific forests and AFFIRMS stations.
8. ENDING YEAR.
   Enter the last year of fire reports and weather data to be processed. Enter only the last two digits of the year and add the decimal point. For example, enter 1980 as "80.". Fire reports and weather observations after this year will not be processed. Consult the NFODL and NFWDL for the most recent years of data available for specific forests and AFFIRMS stations.
9. BEGINNING SEASON DATE.
   Enter the first month and day of fire report and weather observation data to be processed for each year. Use two digits for the month and two digits for the day and add the decimal point. For example, enter January 1 as "0101.". Fire reports and weather observations preceding this date each year will not be processed. Use January 1 if you wish to process the entire year's data.
10. ENDING SEASON DATE.
    Enter the last month and day of fire report and weather observation data to be processed for each year. Use two digits for the month and two digits for the day and add the decimal point. For example, enter December 31 as "1231.". Fire reports and weather observations after this date each year will not be processed. RXBUILD can therefore be used to build data files for a specific season. Use December 31 if you wish to process the entire year's data.
11. NFWDL FILE NAME.
    RXBUILD obtains fire weather observations from the NFWDL archives. The name of the tape file containing observations for the first year of the lowest numbered AFFIRMS station must be supplied by the user. The procedure for obtaining the tape file name is described by Furman and Brink (1975) and for completeness is included in "Part 2—Computer Terminal Operator's Manual." You may wish to leave this item blank for the terminal operator to determine. The entry must be terminated by a period.
12. NUMBER OF DISTRICTS.
    Enter the number of Ranger Districts for which fire reports are to be processed. At least 1 and up to 10 Districts may be requested. Remember to add the decimal point.
13. FIRE REPORT LISTING.
    Enter "YES" if you want a listing of the processed fire reports; otherwise leave blank. The listing contains fire variables 1 through 30 (table 2) for each fire. Fifty fire reports are printed per page.
14. WEATHER DATA FILE LISTING.
    Enter "YES" if you want a listing of the processed daily AFFIRMS weather observations, NFDRS indices, and manning levels; otherwise leave blank. The listing contains variables 31 through 60 (table 2) for each daily observation at each AFFIRMS station. Fifty daily records are printed per page.

Date 3-82

SHEET NO. 4 -- DATE PARAMETERS

7. BEGINNING YEAR. 70.
8. ENDING YEAR. 80.
9. BEGINNING SEASON DATE. 101.
10. ENDING SEASON DATE. 1231.
11. NFWDL FILE NAME. 21-24.
12. NUMBER OF DISTRICTS.[1/] 3.
13. FIRE REPORT LISTING? YES
14. WEATHER DATA FILE LISTING? YES

[1/] Information on each District indicated here included on a Sheet No. 5, District Parameters.

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Exhibit 1f.—Sample RXBUILD Input Worksheet No. 4, Date Parameters.

Sheet No. 5—District Parameters

Sheet No. 5 must be completed for **each** Ranger District declared in item 12, sheet No. 4 (see exhibit 1g for sample). It must immediately follow the date parameter sheet (sheet No. 4). Parameters for up to three Districts may be entered on a single sheet No. 5 (use as many sheet No. 5's as necessary to include information on all Districts indicated in item 12, sheet No. 4).

12.____.1 DISTRICT NAME.
Enter up to 20 letters, numbers, or special characters identifying the Ranger District.

12.____.2 DISTRICT ADP CODE.
Enter the 1- or 2-digit District ADP code used in 5100-29 individual fire reports. Consult the Regional supplement to FSH 5109.14. Remember to add the decimal point.

12.____.3 DISTRICT AFFIRMS STATION.
Enter the **sequence** number (**not** the 6-digit ID) of the AFFIRMS station representing this District. The AFFIRMS stations are sequentially numbered from 1 through 10 in order of increasing 6-digit ID (the same order as listed on Sheet No. 1). In exhibit 1g, the Troy District uses AFFIRMS station number "1." (240112), the Libby and Cabinet District use AFFIRMS station number "2." (240116). Remember to add the decimal point.

Date 3-82

RXBUILD INPUT WORKSHEET

SHEET NO. 5 -- DISTRICT PARAMETERS

DISTRICT NO. 1

12.1.1 DISTRICT NAME. TROY D4

12.1.2 DISTRICT ADP CODE. _4.

12.1.3 DISTRICT AFFIRMS STATION.(TROY-240112) _1.

DISTRICT NO. 2

12.2.1 DISTRICT NAME. LIBBY D5

12.2.2 DISTRICT ADP CODE. _5.

12.2.3 DISTRICT AFFIRMS STATION.(BIG SWEDE-240116) _2.

DISTRICT NO. 3

12.3.1 DISTRICT NAME. CABINET D7

12.3.2 DISTRICT ADP CODE. _7.

12.3.3 DISTRICT AFFIRMS STATION.(BIG SWEDE-240116) _2.

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Exhibit 1g.—Sample RXBUILD Input Worksheet No. 5, District Parameters. Sheet No. 5 must contain information about each Ranger District indicated in item 12, sheet No. 4.

ENTERING RXBUILD INPUT

RXBUILD worksheet items are put in the computer using the DEMAND interactive program CSSG*R1LIB.RXBUILD. The program prompts the terminal operator for each worksheet item, checks each entry for value range and decimal point, and writes it to an RXBUILD directive file. After successfully entering all worksheet items, the directive file can be @ADD'ed at any time to initiate program execution. Details of RXBUILD input entry, initiation, and file maintenance are contained in "Part 2—Computer Terminal Operator's Manual" (Bevins and Fischer 1983).

RXBUILD OUTPUT

Several pages of preliminary material will precede the RXBUILD computer output. This material includes:

1. UNIVAC 1100 job banner; 1 page.
2. EXEC 8 control statements; 1 page.
3. Program FIREDATALIB*PROGRAMS.GETDATA2 output; 1 to 2 pages.
4. Program NFDR78*FIREFAMILY.FIRDAT1 output; 1 title page per AFFIRMS station plus 1 "Summary of Station Statistics" page for each station-year.
5. EXEC 8 control statement for CSSG*R1LIB.RXBUILD; 1 page.

Output printed by RXBUILD includes:

1. RXBUILD banner; 1 page.
2. RXBUILD cover; 1 page.
3. Echo of RXBUILD input file (exhibit 2) created by CSSG*R1LIB.RXBUILD DEMAND data entry; 1 page plus 1 additional page per AFFIRMS station.

If the option to print the fire report file has been selected, additional output includes:

4. Table of fire variable codes, column headings, descriptions, and units of measure; 1 page.
5. Fire report listing (exhibit 3); 1 page per 50 fire reports.

If the option to print the weather observation/NFDRS index file has been selected, additional output includes:

6. Table of weather observation and NFDRS index variable codes, column headings, descriptions, and units of measure; 1 page.
7. Daily fire weather observation/NFDRS index listing (exhibit 4); 1 page per 50 daily observations.

```
 INPUT STREAM FOR RXBUILD
 1.  TITLE.
CABINET WILDERNESS AREA FIRE MANAGEMENT PLAN
 2.  USER NAME.
COLLIN D. BEVINS
 3.  REGION NAME OR NUMBER.
NORTHERN REGION
 4.  FOREST NAME.
KOOTENAI NATIONAL FOREST
 5.  FOREST ADP CODE.
    14
 6.  NUMBER OF AFFIRMS WEATHER STATIONS.
     2
 6. 1.  AFFIRMS STATION NO.  1   6-DIGIT ID.
240112
 6. 1.1.  AFFIRMS STATION NAME.
TROY AFFIRMS
 6. 1.2.  AFFIRMS STATION ELEVATION.
  1950
 6. 1.3.  AFFIRMS STATION LATITUDE.
    48
 6. 1.4.  NFDRS FUEL MODEL.
G
 6. 1.5.  NFDRS SLOPE CLASS.
     3
 6. 1.6.  NFDRS HERBACEOUS TYPE.
P
 6. 1.7.  NFDRS CLIMATE CLASS.
     3
 6. 1.8.  NFDRS GREENUP DATE.
   601
 6. 1.9.  NFDRS FIRST FREEZE DATE.
   915
 6. 1.10.  NFDRS WEEKDAY MAN RISK FACTOR.
   100
 6. 1.11.  NFDRS WEEKEND MAN RISK FACTOR.
   100
 6. 1.12.  NFDRS LIGHTNING SCALING FACTOR.
  1.00
 6. 1.13.  NO. MANNING VARIABLES.
     2
 6. 1.13.1.1.  BASE VARIABLE FOR MANNING VARIABLE NO. 58.
    53
 6. 1.13.1.2.  NO. CLASSES OF MANNING VARIABLE NO. 58.
     5
 6. 1.13.1.3.  90TH PERCENTILE VALUE OF BASE VARIABLE NO. 53.
    62
 6. 1.13.1.3.  97TH PERCENTILE VALUE OF BASE VARIABLE NO. 53.
    69
 6. 1.13.2.1.  BASE VARIABLE FOR MANNING VARIABLE NO. 59.
    56
 6. 1.13.2.2.  NO. CLASSES OF MANNING VARIABLE NO. 59.
     5
 6. 1.13.2.3.  90TH PERCENTILE VALUE OF BASE VARIABLE NO. 56.
    59
 6. 1.13.2.3.  97TH PERCENTILE VALUE OF BASE VARIABLE NO. 56.
    68
 6. 2.  AFFIRMS STATION NO.  2   6-DIGIT ID.
240116
 6. 2.1.  AFFIRMS STATION NAME.
BIG SWEDE MTN.
 6. 2.2.  AFFIRMS STATION ELEVATION.
  4336
 6. 2.3.  AFFIRMS STATION LATITUDE.
    48
 6. 2.4.  NFDRS FUEL MODEL.
G
 6. 2.5.  NFDRS SLOPE CLASS.
     3
 6. 2.6.  NFDRS HERBACEOUS TYPE.
P
 6. 2.7.  NFDRS CLIMATE CLASS.
     3
 6. 2.8.  NFDRS GREENUP DATE.
   601
 6. 2.9.  NFDRS FIRST FREEZE DATE.
   915
 6. 2.10.  NFDRS WEEKDAY MAN RISK FACTOR.
   100
 6. 2.11.  NFDRS WEEKEND MAN RISK FACTOR.
   100
 6. 2.12.  NFDRS LIGHTNING SCALING FACTOR.
  1.00
 6. 2.13.  NO. MANNING VARIABLES.
     2
 6. 2.13.1.1.  BASE VARIABLE FOR MANNING VARIABLE NO. 58.
    53
 6. 2.13.1.2.  NO. CLASSES OF MANNING VARIABLE NO. 58.
     5
 6. 2.13.1.3.  90TH PERCENTILE VALUE OF BASE VARIABLE NO. 53.
    62
 6. 2.13.1.3.  97TH PERCENTILE VALUE OF BASE VARIABLE NO. 53.
    69
 6. 2.13.2.1.  BASE VARIABLE FOR MANNING VARIABLE NO. 59.
    56
 6. 2.13.2.2.  NO. CLASSES OF MANNING VARIABLE NO. 59.
     5
 6. 2.13.2.3.  90TH PERCENTILE VALUE OF BASE VARIABLE NO. 56.
    59
 6. 2.13.2.3.  97TH PERCENTILE VALUE OF BASE VARIABLE NO. 56.
    68
 7.  BEGINNING YEAR.
    70
 8.  ENDING YEAR.
    80
 9.  BEGINNING SEASON DATA.
   101
 10.  ENDING SEASON DATE.
  1231
 11.  NFWDL FILE NAME CONTAINING 24011270.
21-24.
 12.  NUMBER OF DISTRICTS.
     3
 12. 1.1.  DISTRICT NAME.
TROY D4
 12. 1.2.  DISTRICT ADP CODE.
     4
 12. 1.3.  DISTRICT AFFIRMS STATION.
     1
 12. 2.1.  DISTRICT NAME.
LIBBY D5
 12. 2.2.  DISTRICT ADP CODE.
     5
 12. 2.3.  DISTRICT AFFIRMS STATION.
     2
 12. 3.1.  DISTRICT NAME.
CABINET D7
 12. 3.2.  DISTRICT ADP CODE.
     7
 12. 3.3.  DISTRICT AFFIRMS STATION.
     2
 13.  FIRE REPORT FILE LISTING.
     T
 14.  WEATHER DATA FILE LISTING.
     T
```

Exhibit 2.—Sample RXBUILD input echo.

```
SUBROUTINE FIRES PROCESSING LOG.

AG RG NF RD OF JD ST CO WATRSHED NUM YYMMDD W ST GN SP SC  ACRES P HR CNT MAX S A E T CT OFUEL PFUEL LEGAL DESC STN

 1  1 14  5 14  2 24  0 16010000   2 70 413 1  6 10 16  1      0 1 16   1   7 0 9 2 0 94    23     0 031N032W18   2
 1  1 14  5 14  2 24  0 16010000   7 70 5 2 7  3  4 10  1      0 5 16   0   1 0 4 2 0 94    31     0 031N030W32   2
 1  1 14  5 14  1 24  0 16010000   8 70 5 3 1  3 10 10  1      0 5 16   1   3 0 9 3 0 11    31     0 029N031W02   2
 1  1 14  5 14  1 24  0 16010000  11 70 5 4 2  4  7  9  1      0 5 18   0   2 1 7 2 0  0    23     0 031N032W18   2
 1  1 14  4 14  2 24  0 16010000  12 70 5 5 3  5  1 15  3     60 1  9   5   7 0 9 2 0 24    21    11 034N034W05   1
 1  1 14  7 14  4 24  0 16010000  23 70 6 5 6  8 10 27  1      0 6 23   1   5 0 9 2 0 94    31     0 032N029W34   2
 1  1 14  5 14  1 24  0 16010000  21 70 6 6 7  1 10  1  1      0 0 15   1   2 0 2 4 0 43    31     0 029N030W04   2
 1  1 14  5 14  2 24  0 16010000  22 70 6 9 3  1 10  1  1      0 0 14   1   3 0 3 2 0 33    31     0 029N031W12   2
 1  1 14  7 14  1 24  0 16010000  24 70 6 9 3  4  8  9  1      0 5  9   0   2 2 1 3 0  1    31     0 030N029W08   2
 1  1 14  5 14  2 24  0 16010000  29 70 7 3 6  6 10  7  2      1 1 13   3   8 0 9 2 0 94    22     0 031N031W32   2
 1  1 14  4 14  3 24  0 16010000  35 70 7 5 1  5 10 11  2      1 5 11   1   6 5 5 2 0 43    21     0 031N033W18   1
 1  1 14  4 14  2 24  0 16010000  36 70 7 6 2  4  7  8  1      0 7 14   1   4 0 4 2 0 83    12     0 029N033W29   1
 1  1 14  4 14  1 24  0 16010000  39 70 710 6  1 10  1  1      0 0 12   0   5 3 0 4 0 66    31     0 031N029609   1
 1  1 14  7 14  1 24  0 16010000  40 70 710 6  1 10  1  1      0 0 12   1   3 0 0 5 0  3    21     0 030N029W06   2
 1  1 14  7 14  2 24  0 16010000  46 70 716 5  1 10  1  1      0 0 20   6   2 4 3 5 0 33    31     0 030N030W11   2
 1  1 14  4 14  1 24  0 16010000  49 70 716 5  3  8 10  1      0 5 13   1   3 0 2 4 0 11    22     0 030N034W16   1
 1  1 14  4 14  1 24  0 16010000  50 70 716 5  1 10  1  1      0 0 16   6   2 8 4 3 0 13    12     0 029N034W23   1
 1  1 14  4 14  1 24  0 16010000  51 70 716 5  1 10  1  1      0 0 20   1   3 3 0 5 0 93    22     0 032N033W28   1
 1  1 14  4 14  1 24  0 16010000  52 70 716 5  1 10  1  1      0 0 19  10   2 0 2 4 0 13    22     0 032N033W28   1
 1  1 14  4 14  1 10  0 16010000  53 70 716 5  1 10  1  1      0 0 19   2   2 2 0 5 0 83    32     0 059N003E10   1
 1  1 14  4 14  1 24  0 16010000  79 70 716 5  1 10  1  1      0 0 18   4   2 3 1 4 0 83    22     0 029N034W23   1
 1  1 14  4 14  1 24  0 16010000  82 70 716 5  1 10  1  1      0 0 20   2   2 8 0 4 0 13    22     0 029N034W25   1
 1  1 14  5 14  1 24  0 16010000  85 70 716 5  1 10  1  1      0 0 19   1   3 6 1 3 0 43    32     0 031N032W11   2
 1  1 14  5 14  1 24  0 16010000  86 70 716 5  1 10  1  1      0 0 21   3   3 5 1 4 0  3    31     0 030N030W03   2
 1  1 14  5 14  1 24  0 16010000  88 70 716 5  1 10  1  1      0 0 21   1   2 4 6 3 0 33    21     0 031N031W19   2
 1  1 14  7 14  1 24  0 16010000  47 70 717 6  1 10  1  1      0 0  1   5   4 4 3 4 0  1    21     0 032N028W06   2
 1  1 14  4 14  1 24  0 16010000  54 70 717 6  1 10  1  1      0 0  4   8   5 7 3 6 0 91    12     0 032N033W14   1
 1  1 14  4 14  1 24  0 16010000  55 70 717 6  1 10  1  2      0 0  2   5   7 2 2 4 0 12    23     0 030N035W26   1
 1  1 14  4 14  1 24  0 16010000  78 70 717 6  1 10  1  1      0 0 19   3   2 4 1 5 0 83    12     0 029N034W23   1
 1  1 14  4 14  1 24  0 16010000  81 70 717 6  1 10  1  2      6 0  4  23  25 4 0 4 0 86    22     0 030N035W12   1
 1  1 14  5 14  2 24  0 16010000  87 70 717 6  1 10  1  1      0 0 23   1   3 8 7 2 0  3    31     0 030N031W02   2
 1  1 14  5 14  1 24  0 16010000  89 70 717 6  1 10  1  1      0 0 23   2   2 2 5 6 0 62    22     0 033N032W27   2
 1  1 14  5 14  1 24  0 16010000  90 70 717 6  1 10  1  1      0 0 22   1   2 1 2 3 0 62    32     0 032N032W27   2
 1  1 14  5 14  1 24  0 16010000  91 70 717 6  1 10  1  1      0 0 23   3   9 5 2 4 0 15    31     0 029N030W33   2
 1  1 14  5 14  1 24  0 16010000  92 70 717 6  1 10  1  1      0 0 23   2   2 8 7 7 0 53    23     0 030W032W15   2
 1  1 14  5 14  1 24  0 16010000  93 70 717 6  1 10  1  1      0 0  1   1   3 2 7 3 0  5    31     0 029N030W22   2
 1  1 14  5 14  1 24  0 16010000  98 70 717 6  1 10  1  1      0 0 19   2   2 3 5 7 0 91    31     0 031N032W28   2
 1  1 14  7 14  1 24  0 16010000 114 70 717 6  1 10  1  1      0 0  1   1   2 6 7 3 0  2    32     0 031N029W34   2
 1  1 14  7 14  1 24  0 16010000 115 70 717 6  1 10  1  1      0 0 20   0   3 0 0 5 0 61    22     0 031N027W16   2
 1  1 14  7 14  1 24  0 16010000 116 70 717 6  1 10  1  1      0 0 24   1   2 3 1 5 0 13    22     0 033N028W31   2
 1  1 14  7 14  1 24  0 16010000 117 70 717 6  1 10  1  1      0 0  1   4   3 7 2 4 0 33    22     0 033N029W33   2
 1  1 14  7 14  1 24  0 16010000 118 70 717 6  1 10  1  1      0 0 24   2   2 1 5 4 0 23    31     0 030N029W15   2
 1  1 14  7 14  2 24  0 16010000 119 70 717 6  1 10  1  2      1 0 24   3   3 0 3 3 0  3    22     0 031N029W14   2
 1  1 14  7 14  1 24  0 16010000 120 70 717 6  1 10  1  1      0 0 23   4   2 1 0 5 0 23    21     0 032N030W27   2
 1  1 14  7 14  2 24  0 16010000 125 70 717 6  1 10  1  2      3 0 21  29   5 4 2 5 0 43    31     0 030N029W35   2
 1  1 14  4 14  1 24  0 16010200 132 70 717 6  1 10  1  1      0 0  4   1   3 1 1 3 0 83    22     0 034N033W08   1
 1  1 14  4 14  1 24  0 16010000  80 70 718 7  1 10  1  1      0 0 22   2   3 7 5 4 0 53    22     0 029N034W28   1
 1  1 14  5 14  1 24  0 16010000  94 70 718 7  1 10  1  1      0 0  1  14   4 3 1 4 0  3    31     0 031N031W07   2
 1  1 14  5 14  1 24  0 16010000  95 70 718 7  1 10  1  1      0 0  2   3   3 4 1 3 0 32    23     0 032N031W15   2
```

Exhibit 3.—Sample RXBUILD fire file listing.

```
AFFIRMS STATION NO.  1
MM/DD/YY JUL SW  T RH WD WS TX TN HX HN PD PT PA LA  MR   1  10 100  TH  WD  HB IC SC ER MO LO BI FL M1 M2 M3 ADDRESS

 6/15/70 167  4 59 68  4  7  0  0  0  0  0  0  0  1 100 145 230 188 246  76  25  3  8  9  3  0 22 16  2  2  0    1661
 6/16/70 168  4 58 83  4 10  0  0  0  0  0  0  0  1 100 194 270 190 244  82  40  0  8  6  0  0 18 13  2  2  0    1671
 6/17/70 169  1 78 41  4  3  0  0  0  0  0  0  0  1 100  82 160 172 239  87  40 15  6 16 15  0 25 21  2  2  0    1681
 6/18/70 170  2 83 36  0  0  0  0  0  0  0  0  0  1 100  63  78 157 233  92  48 19  5 21 19  0 26 23  2  2  0    1691
 6/19/70 171  0 88 24  8  6  0  0  0  0  0  0  0  1 100  56 140 143 227  96  55 32  9 22 32  0 34 33  2  3  0    1701
 6/20/70 172  0 88 24  0  0  0  0  0  0  0  0  0  1 100  46  90 133 221 100  62 28  6 25 28  0 29 29  2  2  0    1711
 6/21/70 173  0 88 24  0  0 94 50 88 19  0  0  0  1 100  46  90 121 214 103  68 28  5 28 28  0 30 29  2  3  0    1721
 6/22/70 174  0 90 15  7  4 94 56 50  8  0  0  0  1 100  33  70  97 206 105  72 42  8 33 42  0 39 41  3  3  0    1731
 6/23/70 175  0 96 14  3  4 96 44 70  6  0  0  0  1 100  31  70  85 199 106  75 44  8 36 44  0 41 43  3  3  0    1741
 6/24/70 176  0 88 22  3 11 97 52 66  8  0  0  0  1 100  42  80  75 192 107  78 49 15 37 49  0 55 52  3  3  0    1751
 6/25/70 177  0 92 17  4  5 92 44 72  8  0  0  0  1 100  34  70  71 185 108  80 42  9 40 42  0 44 43  3  3  0    1761
 6/26/70 178  2 89 34  7  3 93 66 68 21  0  0  0  1 100  66 100  71 179 108  83 19  6 39 19  0 36 29  3  3  0    1771
 6/27/70 179  3 80 39  4  8 91 60 74 39  0  0  0  1 100  78 100  79 174 109  85 18  9 38 18  0 44 34  3  3  0    1781
 6/28/70 180  2 70 35  4  6 72 56 70 22  0  0  0  1 100  71 110  78 169 128  85 18  7 40 18  0 40 31  3  3  0    1791
 6/29/70 181  3 67 32  4  7 70 42 78 22  0  0  0  1 100  72 110  81 165 125  87 18  8 40 18  0 42 32  3  3  0    1801
 6/30/70 182  3 63 40  4 10 68 48 62 26  0  0  0  1 100  87 130  79 161 121  87 15 10 40 15  0 47 35  3  3  0    1811
 7/ 1/70 183  2 76 36  4 14 79 35 76 22  0  0  0  1 100  72 110  81 157 117  87 27 15 42 27  0 58 45  3  3  0    1821
 7/ 2/70 184  1 82 32  2  3 82 47 72 21  0  0  0  1 100  58  90  80 153 114  87 22  6 45 22  0 39 32  3  3  0    1831
 7/ 3/70 185  0 94 26  4  3 94 46 71 16  0  0  0  1 100  45  80  77 149 110  85 31  6 48 31  0 42 37  3  3  0    1841
 7/ 4/70 186  0 97 22  6  4 97 53 74 14  0  0  0  1 100  31  30  75 145 106  83 44  8 53 44  0 49 47  3  3  0    1851
 7/ 5/70 187  0 92 17  5  6 98 55 72 10  0  0  0  1 100  24  20  72 140 102  95 53 10 55 53  0 54 54  3  3  0    1861
 7/ 6/70 188  0 88 24  4  6 93 44 30  8  0  0  0  1 100  36  40  60 136  98  90 43  9 56 43  0 54 49  3  3  0    1871
 7/ 7/70 189  0 96 16  2  3 96 46 69 10  0  0  0  1 100  23  20  61 132  95  86 48  8 60 48  0 51 50  3  3  0    1881
 7/ 8/70 190  0 95 17  8  9 97 49 70  8  0  0  0  1 100  24  20  60 128  92  83 66 15 61 66  0 68 67  3  4  0    1891
 7/ 9/70 191  1 98 14  4  4 99 51 76 10  0  0  0  1 100  23  20  63 125  89  80 52  9 62 52  0 55 54  3  3  0    1901
 7/10/70 192  3 86 30  4  7100 55 66 20  0  0  0  1 100  53  40  65 122  86  77 30 10 59 30  0 57 46  3  3  0    1911
 7/11/70 193  1 89 18  4  8 90 52 69 11  0  0  0  1 100  30  30  65 119  83  74 55 14 63 55  0 67 61  4  4  0    1921
 7/12/70 194  8 62 89  4  5 89 51 89 38  1  0  1  1 100 200 200  86 119  84  74  0  4 40  0  0 32 23  3  3  0    1931
 7/13/70 195  8 74 38  3  8 74 53 71 38  1  0  4  1 100  67  50  93 120  84  74 24 11 55 24  0 56 43  3  3  0    1941
 7/14/70 196  1 89 16  4  2 89 47 76 16  0  0  0  1 100  28  30  88 118  83  73 42  7 60 42  0 50 46  3  3  0    1951
 7/15/70 197  0 93 21  3  5 93 43 72  9  0  0  0  1 100  30  30  81 116  81  70 49 10 62 49  0 58 54  3  3  0    1961
 7/16/70 198  1 92 31  7  6 95 49 66  9  0  0  0  1 100  44  30  74 113  78  68 39 10 63 39  0 59 50  4  3  0    1971
 7/17/70 199  1 86 32  4  5 97 60 78 20  3  0 15  1 100  47  40  90 116  81  69 34  9 58 34  0 54 45  3  3  0    1981
 7/18/70 200  1 91 22  7  4 93 50 73  8  0  0  0  1 100  34  30  82 114  79  67 43  9 62 43  0 55 50  3  3  0    1991
 7/19/70 201  1 96 21  5  4 97 50 70  7  0  0  0  1 100  33  30  75 110  76  64 45  9 64 45  0 57 52  4  3  0    2001
 7/20/70 202  0 97 16  4  4 99 50 73 10  0  0  0  1 100  23  20  73 108  74  62 57 10 67 57  0 61 59  4  4  0    2011
 7/21/70 203  2 81 26  4 10 97 56 72 20  0  0  0  1 100  45  40  74 107  73  60 45 16 64 45  0 73 61  4  5  0    2021
 7/22/70 204  3 66 63  4  3 80 57 68 18  1  0  4  1 100 109 100  78 107  73  60  7  6 56  7  0 43 31  3  3  0    2031
 7/23/70 205  1 84 19  7  7 84 41 80 12  0  0  0  1 100  32  30  79 106  72  60 52 13 66 52  0 68 61  4  4  0    2041
 7/24/70 206  2 86 18  5 10 86 44 71 12  0  0  0  1 100  33  30  76 103  69  57 58 18 67 58  0 78 69  4  5  0    2051
 7/25/70 207  3 63 70  3  7 84 58 70 25  1  0  1  1 100 127 120  82 104  70  57  6  9 54  6  0 51 36  3  3  0    2061
 7/26/70 208  3 70 65  7  4 72 51 77 45  1  0  2  1 100 110  90  95 105  71  58  8  7 55  8  0 45 32  3  3  0    2071
 7/27/70 209  2 89 25  5  3 89 51 60 22  0  0  0  1 100  43  40  87 104  70  56 34  8 64 34  0 53 45  4  3  0    2081
 7/28/70 210  4 66 85  0  0 89 58 85 26  6  0 28  1 100 186 231 119 113  78  61  0  3 38  0  0 27 19  3  2  0    2091
 7/29/70 211  2 74 32  6  6 75 48 82 18  0  0  0  1 100  58  73 110 112  77  61 27 10 55 27  0 54 43  3  3  0    2101
 7/30/70 212  2 75 26  2  4 76 49 74 19  1  0  1  1 100  46  40 106 113  78  61 31  8 58 31  0 52 43  3  3  0    2111
 7/31/70 213  1 77 34  2  1 80 38100 30  0  0  0  1 100  55  68 117 114  79  62 23  6 54 23  0 43 35  3  3  0    2121
 8/ 1/70 214  0 89 18  7  5 90 40 79 11  0  0  0  1 100  28  30 106 113  78  61 53 11 60 53  0 59 56  3  3  0    2131
 8/ 2/70 215  6 57 94  4  1 90 54100 34  7  0 32  1 100 226 220 145 124  88  67  0  0 31  0  0  0  0  2  1  0    2141
```

Exhibit 4.—Sample RXBUILD weather file listing.

Program RXFIRES

RXFIRES INPUT

The input requirements to program RXFIRES include run identification, fire exclusion criteria, fire suppression criteria, and output options. A set of RXFIRES worksheets facilitate organization, documentation, and proper entry of the required inputs. All input items on the worksheets have reference numbers corresponding to the following instructions. A set of RXFIRES worksheets suitable for reproduction is included as appendix B.

Properly completed RXFIRES input worksheets accompany the instructions that follow. These sample worksheets demonstrate all program RXFIRES options. The example is a continuation of the Cabinet Wilderness scenario used to demonstrate program RXBUILD input.

RXFIRES INPUT WORKSHEET INSTRUCTIONS

There is one overriding rule for input entry:

ALL NUMERIC ENTRIES **MUST** INCLUDE A DECIMAL POINT!

In the case of whole numbers, the decimal point must be appended. For example, the number "twelve" must be entered as "12.".

There are three separate RXFIRES input worksheets:

Sheet No. 1 — Run Identification and Output Level (1 per run)
Sheet No. 2 — Fire Exclusion Criteria (as needed)
Sheet No. 3 — Fire Suppression Criteria (as needed)

Sheet No. 1—Run Identification and Output Level

Refer to exhibit 5a for example of completed sheet No. 1.

1. RUN NAME.
   Enter any information desired to identify the test prescription run. You may use up to 80 letters, numbers, or special characters.
2. USER NAME.
   Enter your name or other identifying information. You may use up to 80 letters, numbers, or special characters.
3. FIRE EXCLUSION CRITERIA.
   See instruction for sheet No. 2.
4. FIRE SUPPRESSION CRITERIA.
   See instruction for sheet No. 3.
5. OUTPUT LEVEL.
   Enter level 1., 2., or 3., and include the decimal point.

Level 1. Print yearly summary table only.

Level 2. Print yearly summary table and individual unscheduled prescribed fire case histories.

Level 3. Print yearly summary table, unscheduled prescribed fire case histories, and daily fire load summary table.

Enter Items 5.1 and 5.2 only if output level 2 or 3 is requested.

Enter Item 5.3 only if output level 3 is selected.

5.1 INCHES OF PRECIPITATION.
Enter only if you selected output levels 2. or 3. Enter the inches of precipitation in a 24-hour period required to extinguish a fire. In the example in exhibit 5a, 0.45 inches of rain was selected.

5.2 FIRE CASE HISTORY VARIABLES.
Enter up to 12 codes of variables to be printed in the fire case histories. Select variable codes from table 2 and include the decimal point. In exhibit 6a, county (variable 8.), watershed (variable 9.), weekday (14.), acres burned (19.), hours to control (22.), maximum number of suppression personnel (23.), ignition component (51.), spread component (52.), energy release component (53.), and burning index (56.) will be printed for each unscheduled prescribed fire.

5.3 FIRE LOAD SUMMARY TABLE DATES.
Enter the first and last dates and years for which daily fire loads are computed. Selected dates do not have to correspond to those specified for RXBUILD input. Caution: selection of all days from January 1 through December 31 will result in a high percentage of days with no wildfires and no prescribed fires. In the example in exhibit 5a, fire load will be determined for all years (1970. through 1980.) during the traditional fire season only (June 1 through September 20). Enter the dates using two digits for the month and two digits for the day, and add the decimal point. For example, enter June 1 as "0601." and September 20 as "0920.".

Date 3-82

RXFIRES INPUT WORKSHEET

SHEET NO. 1 -- RUN IDENTIFICATION

1. RUN NAME.

CABINET WILDERNESS FIRE MANAGEMENT PLAN

2. USER NAME.

COLLIN BEVINS

3. EXCLUSION CRITERIA. (Use Sheet No. 2)

4. FIRE SUPPRESSION CRITERIA. (Use Sheet No. 3)

5. OUTPUT LEVEL. 3.

5.1 INCHES OF PRECIPITATION. 0.45

5.2 FIRE CASE HISTORY VARIABLES.

01.	02.	03.	04.	05.	06.	07.	08.	09.	10.	11.	12.
8.	9.	14.	19.	22.	23.	51.	52.	53.	56.		

5.3 FIRE LOAD SUMMARY TABLE DATES.

First MMDD.	Last MMDD.	First YEAR.	Last YEAR.
0601.	0920.	1970.	1980.

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Exhibit 5a.—Sample RXFIRES Input Worksheet No. 1, Run Identification.

Sheet No. 2—Fire Exclusion Criteria

Refer to exhibit 5b for example of completed sheet No. 2. The fire exclusion criteria apply the following test to each fire report:

EXCLUDE IF VARIABLE NO. (code) IS (argument) (value).Only Items 3.1 (VARIABLE CODE), 3.2 (ARITHMETIC ARGUMENT), and 3.3 (VARIABLE VALUE), are entered into the computer. Items 3.4 (VARIABLE NAME) and 3.5 (VARIABLE MEASURE) are for documentation purposes only and are optional.

3.1 VARIABLE CODE.

Enter the 1- or 2-digit variable code (table 2) for each fire exclusion criterion. Include the decimal point.

3.2 ARITHMETIC ARGUMENT.

Enter one of the following arithmetic arguments:

EQ — equals
NE — does not equal
LT — is less than
LE — is less than or equal to
GT — is greater than
GE — is greater than or equal to

3.3 VARIABLE VALUE.

Enter the value of the variable and add the decimal point. NOTE: be sure to use the correct variable value. Many of the variables, such as elevation, use coded rather than absolute values. To exclude fires below 4,500 feet elevation, for example, use:

EXCLUDE IF 26. LT 4.
and not:
EXCLUDE IF 26. LT 4500.

You must also exercise caution when specifying units of measure. Dead fuel moistures, for example, are measured in 10ths of a percent, and not whole percents. To exclude fire reports when 10-hour fuel moisture is above 20 percent, use:

EXCLUDE IF 46. GT 200.
and not:
EXCLUDE IF 46. GT 20.

The latter will exclude all fires when 10-hour fuel moisture is greater than 2 percent. Consult table 2 for proper variable value codes and units of measure.

3.4 VARIABLE NAME.

For documentation purposes, enter the variable name. This item is not entered in program RXFIRES.

3.5 VARIABLE MEASURE.

For documentation and error-checking, enter the actual variable value. For example, to document use of elevation value code "4", enter "4500 feet" as the variable measure requested.

Date 3-82 RXFIRES INPUT WORKSHEET

SHEET NO. 2 -- FIRE EXCLUSION CRITERIA

EXCLUDE FIRES IF:

3.1 VARIABLE CODE	3.2 ARITHMETIC ARGUMENT	3.3 VALUE CODE	3.4 VARIABLE NAME	3.5 VARIABLE MEASURE
26.	LT	4.	ELEVATION	4500 FT.
4.	LT	4.		
4.	GT	7.	DISTRICT *	
4.	EQ	6.		
		.		
		.		
		.		

* EXCLUDE ALL DISTRICTS EXCEPT:

		.	TROY (4)	
		.	LIBBY (5)	
		.	CABINET (7)	
		.		
		.		
		.		
		.		
		.		
		.		
		.		
		.		
		.		
		.		

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Exhibit 5b.—Sample RXFIRES Input Worksheet No. 2, Fire Exclusion Criteria.

Sheet No. 3—Fire Suppression Criteria

Refer to exhibit 5c for example of completed sheet No. 3. The fire suppression criteria apply the following test to each fire report:

SUPPRESS IF VARIABLE NO. (code) IS (argument) (value) THE PREVIOUS (n) DAYS.

Only Items 4.1 (VARIABLE CODE), 4.2 (ARITHMETIC ARGUMENT), 4.3 (VARIABLE VALUE), and 4.4 (PREVIEWED DAYS), are entered into the computer. Items 4.5 (VARIABLE NAME) and 4.6 (VARIABLE MEASURE) are for documentation purpose only and are optional.

4.1 VARIABLE CODE.

Enter the 1- or 2-digit variable code (table 2) for each suppression criteria. Include the decimal point.

4.2 ARITHMETIC ARGUMENT.

Enter one of the following arithmetic arguments:

EQ — equals
NE — does not equal
LT — is less than
LE — is less than or equal to
GT — is greater than
GE — is greater than or equal to

4.3 VARIABLE VALUE.

Enter the value of the variable and add the decimal point.

NOTE: Be sure to use the correct variable value. Refer to the instructions for item 3.3, sheet No. 2. Consult table 2 for proper variable value codes and units of measure.

4.4 PREVIEWED DAYS.

Enter the number of days the suppression criterion is enforced preceding each fire. If the suppression criterion is met on any of the specified number of days preceding the fire's ignition, it is declared a wildfire. This entry may be left blank. If used, be sure to add the decimal point.

4.5 VARIABLE NAME.

For documentation purposes, enter the variable name. This item is not entered into program RXFIRES.

4.6 VARIABLE MEASURE.

For documentation and error-checking, enter the actual variable measure selected. For example, to document use of elevation value code "4", enter "4500 feet" as the variable measure.

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RXFIRES INPUT WORKSHEET

SHEET NO. 3 -- FIRE SUPPRESSION CRITERIA

SUPPRESS FIRES IF:

4.1 VARIABLE CODE	4.2 ARITHMETIC ARGUMENT	4.3 VALUE CODE	4.4 PREVIEW DAYS	4.5 VARIABLE NAME	4.6 VARIABLE MEASURE
15.	NE	1.		CAUSE	LIGHTNING
53.	GT	47.	4.	ERC	80 PERCENTILE
		.			
		.			
		.			
		.			
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		.			

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Exhibit 5c.—Sample RXFIRES Input Worksheet No. 3, Fire Suppression Criteria.

RXFIRES INPUT ENTRY

RXFIRES worksheet items are put into the computer using the DEMAND interactive program CSSG*R1LIB.RXFIRES. The program prompts the terminal operator for each worksheet item, checks each entry for value range and decimal point, and writes it to an RXFIRES directive file. After successfully entering all worksheet items, the directive file can be @ADD'ed at any time to initiate program execution. Details of RXFIRES input entry, initiation, and file maintenance are contained in "Part 2—Computer Terminal Operator's Manual" (Bevins and Fischer 1983).

RXFIRES OUTPUT

Output printed by RXFIRES includes:

1. RXFIRES banner; 1 page.
2. RXFIRES cover, 1 page.
3. Echo of RXFIRES input directive file (exhibit 6); 1 page.
4. Yearly summary of fires by size class and type (exhibit 7); 1 page.
5. Unscheduled fire case histories, if requested (exhibit 8); up to 7 case histories per page.
6. Fire load summary table (exhibit 9); 1 page.

Two types of warning messages may be printed between the input echo page and the yearly fire summary table:

*** WARNING — NO WEATHER DATA ON **date** AT STATION **number** FOR FIRE NO. **Supervisor's number**, FOREST **Forest ADP code**, DISTRICT **District ADP code**, (ADDRESS = **weather file address**) ***.

The message indicates that no weather observations were taken the day the fire started. The fire is automatically excluded from the test prescription analysis.

The second warning message is:

*** NO WEATHER DATA FOR STATION **number** DAY **number** PRECEDING FIRE NO. **Supervisor's number** ON **date** ***.

The message indicates that no weather observations were taken on a day preceding the fire start. The fire is included in the analysis as a wildfire.

```
RXFIRES INPUT STREAM
1. RUN NAME.
CABINET WILDERNESS AREA FIRE MANAGEMENT PLAN
2. USER NAME.
COLLIN D. BEVINS
3. EXCLUSION CRITERIA.
 4
26 LT          4
 4 LT          4
 4 GT          7
 4 EQ          6
4. SUPPRESSION CRITERIA.
 2
15 NE          1   0
53 GT         47   4
5. OUTPUT LEVEL.
3
 .45
 8  9 14 19 22 23 51 52 53 56  0  0
 6 1  920 1970 1980
```

Exhibit 6.—Sample RXFIRES input echo.

```
YEARLY PRESCRIBED (UNSCHEDULED) FIRE OCCURRENCE SUMMARY TABLE  (OUTPUT LEVEL 1)

      TOTAL FIRES REPORTED   FIRES  NOT  EXCLUDED       WILDFIRES          PRESCRIBED FIRES       ESCAPED  RX  FIRES
YEAR     A   B   C  D+ TOT      A   B   C  D+ TOT     A   B   C  D+ TOT     A   B   C  D+ TOT     A   B   C  D+ TOT
----  -------------------   -------------------   -------------------   -------------------   -------------------

1970   102  23   2   2 129     53  13   0   1  67    36  10   0   1  47    17   3   0   0  20     0   0   0   0   0

1971    36   8   0   0  44     11   3   0   0  14     5   0   0   0   5     6   3   0   0   9     0   0   0   0   0

1972    32   5   0   0  37      8   0   0   0   8     1   0   0   0   1     7   0   0   0   7     0   0   0   0   0

1973    67  18   3   0  88     18   5   2   0  25    18   5   2   0  25     0   0   0   0   0     0   0   0   0   0

1974    68  13   3   0  84     22   4   1   0  27     4   1   1   0   6    18   3   0   0  21     5   2   0   0   7

1975    49   9   0   0  58     10   4   0   0  14     5   4   0   0   9     5   0   0   0   5     1   0   0   0   1

1976    37  10   0   0  47      7   0   0   0   7     3   0   0   0   3     4   0   0   0   4     4   0   0   0   4

1977    58  23   2   0  83     14   8   0   0  22     5   4   0   0   9     9   4   0   0  13     2   1   0   0   3

1978    20   1   0   0  21      7   0   0   0   7     7   0   0   0   7     0   0   0   0   0     0   0   0   0   0

1979    50  13   3   3  69     22   7   2   1  32    15   4   2   1  22     7   3   0   0  10     2   1   0   0   3

TOTL   519 123  13   5 660    172  44   5   2 223    99  28   5   2 134    73  16   0   0  89    14   4   0   0  18
```

Exhibit 7.—Sample RXFIRES yearly summary table.

```
-----------------------------------------------------------------------------------------------------------------------------------
-----------------------------------------------------------------------------------------------------------------------------------

NO.  86 FIRE NO. 112 SPECIFIC CAUSE  1 ON  8/10/79 AT FOREST  14 DISTRICT  4 (LOCATION 060N003E32)

           COUNTY  WATRSHED  WEEK DAY  AC BURND  HR CNTRL  MAX PERS        IC        SC       ERC       BI
                0  16010000         6         0         1         6        31         7        46        42
         FIRE REMAINED IN PRESCRIPTION FOR  68 DAYS WHEN IT WAS PRESUMED EXTINGUISHED (DUE TO PRECIPT)

-----------------------------------------------------------------------------------------------------------------------------------
-----------------------------------------------------------------------------------------------------------------------------------

NO.  87 FIRE NO. 148 SPECIFIC CAUSE  1 ON  8/27/79 AT FOREST  14 DISTRICT  5 (LOCATION 028N029W06)

           COUNTY  WATRSHED  WEEK DAY  AC BURND  HR CNTRL  MAX PERS        IC        SC       ERC       BI
                0  16010000         2         0         1         4        22         9        38        44
         FIRE REMAINED IN PRESCRIPTION FOR  43 DAYS WHEN IT EXCEEDED PRESCRIPTION ( 53 GT       47).

-----------------------------------------------------------------------------------------------------------------------------------
-----------------------------------------------------------------------------------------------------------------------------------

NO.  88 FIRE NO. 144 SPECIFIC CAUSE  1 ON  8/28/79 AT FOREST  14 DISTRICT  5 (LOCATION 029N032W24)

           COUNTY  WATRSHED  WEEK DAY  AC BURND  HR CNTRL  MAX PERS        IC        SC       ERC       BI
                0  16010000         3         1        23         4        15         5        41        34
         FIRE REMAINED IN PRESCRIPTION FOR  42 DAYS WHEN IT EXCEEDED PRESCRIPTION ( 53 GT       47).

-----------------------------------------------------------------------------------------------------------------------------------
-----------------------------------------------------------------------------------------------------------------------------------

NO.  89 FIRE NO. 150 SPECIFIC CAUSE  1 ON  8/30/79 AT FOREST  14 DISTRICT  4 (LOCATION 029N034W28)

           COUNTY  WATRSHED  WEEK DAY  AC BURND  HR CNTRL  MAX PERS        IC        SC       ERC       BI
                0  16010000         5         0         7         5        22        10        31        42
         FIRE REMAINED IN PRESCRIPTION FOR  48 DAYS WHEN IT WAS PRESUMED EXTINGUISHED (DUE TO PRECIPT)

-----------------------------------------------------------------------------------------------------------------------------------

         >>> NO WEATHER DATA FOR STATION  2 DAY  1 PRECEEDING FIRE NO. 153 ON  901, 1979. <<<

         >>> NO WEATHER DATA FOR STATION  2 DAY  1 PRECEEDING FIRE NO. 160 ON  917, 1979. <<<

         *** WARNING -- NO WEATHER DATA ON SEP 29, 1979 AT STATION  2 FOR FIRE NO. 167, FOREST 14, DISTRICT  7 (ADDRESS=35662).

         >>> NO WEATHER DATA FOR STATION  2 DAY  1 PRECEEDING FIRE NO. 165 ON 1001, 1979. <<<


  89 PRESCRIBED (UNSCHEDULED) FIRES WERE REPORTED.
```

Exhibit 8.—Sample RXFIRES fire case history listing.

```
                      TABLE 2  --  DAILY FIRE LOAD SUMMARY  (OUTPUT LEVEL 3)

        DAYS (AND % OF TOTAL DAYS) WITH X ONGOING PRESCRIBED (UNSCHEDULED) FIRES AND Y ONGOING WILDFIRES


  ONGOING                                   ONGOING PRESCRIBED FIRES
 WILDFIRES
                   0        1        2        3        4        5        6        7        8        9       10+      TOTL
-----------    -------- -------- -------- -------- -------- -------- -------- -------- -------- -------- -------- --------

     0              745      101       43       58       54       22       33       13       31       41       16     1157
               ( 60.5%) (  8.2%) (  3.5%) (  4.7%) (  4.4%) (  1.8%) (  2.7%) (  1.1%) (  2.5%) (  3.3%) (  1.3%) ( 93.9%)

     1               14       10        3        4        4        0        2        1        4        6        3       51
               (  1.1%) (   .8%) (   .2%) (   .3%) (   .3%) (   .0%) (   .2%) (   .1%) (   .3%) (   .5%) (   .2%) (  4.1%)

     2                5        0        0        2        0        0        0        2        0        1        1       11
               (   .4%) (   .0%) (   .0%) (   .2%) (   .0%) (   .0%) (   .0%) (   .2%) (   .0%) (   .1%) (   .1%) (   .9%)

     3                0        0        1        0        1        0        1        0        1        0        1        5
               (   .0%) (   .0%) (   .1%) (   .0%) (   .1%) (   .0%) (   .1%) (   .0%) (   .1%) (   .0%) (   .1%) (   .4%)

     4                2        0        0        0        0        0        0        0        0        0        0        2
               (   .2%) (   .0%) (   .0%) (   .0%) (   .0%) (   .0%) (   .0%) (   .0%) (   .0%) (   .0%) (   .0%) (   .2%)

     5                0        0        0        0        0        0        1        1        0        0        0        2
               (   .0%) (   .0%) (   .0%) (   .0%) (   .0%) (   .0%) (   .1%) (   .1%) (   .0%) (   .0%) (   .0%) (   .2%)

     6                0        0        0        0        1        0        0        0        0        0        0        1
               (   .0%) (   .0%) (   .0%) (   .0%) (   .1%) (   .0%) (   .0%) (   .0%) (   .0%) (   .0%) (   .0%) (   .1%)

     7                0        0        0        0        0        0        0        0        0        0        0        0
               (   .0%) (   .0%) (   .0%) (   .0%) (   .0%) (   .0%) (   .0%) (   .0%) (   .0%) (   .0%) (   .0%) (   .0%)

     8                0        1        0        0        0        0        0        0        0        0        0        1
               (   .0%) (   .1%) (   .0%) (   .0%) (   .0%) (   .0%) (   .0%) (   .0%) (   .0%) (   .0%) (   .0%) (   .1%)

     9                0        0        0        0        0        0        0        0        0        0        0        0
               (   .0%) (   .0%) (   .0%) (   .0%) (   .0%) (   .0%) (   .0%) (   .0%) (   .0%) (   .0%) (   .0%) (   .0%)

    10+               2        0        0        0        0        0        0        0        0        0        0        2
               (   .2%) (   .0%) (   .0%) (   .0%) (   .0%) (   .0%) (   .0%) (   .0%) (   .0%) (   .0%) (   .0%) (   .2%)

    TOTL            768      112       47       64       60       22       37       17       36       48       21     1232
               ( 62.3%) (  9.1%) (  3.8%) (  5.2%) (  4.9%) (  1.8%) (  3.0%) (  1.4%) (  2.9%) (  3.9%) (  1.7%) (100.0%)


PROGRAM CSSG*R1LIB.RXBUILD2 TERMINATED
DATE:042382       TIME:234636
ERRORS:      0
```

Exhibit 9.—Sample RXFIRES daily fire load summary table.

FIRE MANAGEMENT APPLICATION

The computer system described herein gives the fire management planner a capability to objectively compare the relative performance of alternative fire prescriptions involving the planned use of natural or accidental ignitions. The major products of the system are the yearly prescribed fire occurrence summary table (exhibit 7), the fire case history listing (exhibit 8), and the fire load summary table (exhibit 9). It is important to remember, however, that the numbers presented in the output tables (exhibits 7 and 9) are not estimates of probable future fire occurrence. Rather, they represent a hypothetical performance of a test prescription based on past fire occurrence as constrained by basic assumptions and inherent limitations of the computer programs.

The values generated by program RXFIRES provide a numerical measure of performance of a test prescription. This provides a basis for assessing the type and level of fire activity that might be expected, over time, were the test prescriptions implemented. Generalizations are possible concerning the probable level of prescribed fire activity, probable size of fires, escape potential, and probable co-occurrence of wildfires and prescribed fires.

The utility of such information is, therefore, how the values differ between test prescriptions. For example, over a 10-year period test prescription A will probably result in threefold as many fires as test prescription B. Or, the probability of prescribed fires eventually exceeding prescribed conditions (escapes) is twice as great with test prescription X as it is with test prescription Y.

The fire case history listing (exhibit 8) can be used to determine how a given test prescription might be adjusted to change its performance.

PUBLICATIONS CITED

Bevins, Collin D.; Fischer, William C. A computer system for testing fire management prescriptions. Part 2—computer terminal operator's manual. Gen. Tech. Rep. INT-156. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1983. 22 p.

Bradshaw, Larry S.; Fischer, William C. A computer system for scheduling fire use. Part I: The system. Gen. Tech. Rep. INT-91. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1981a. 63 p.

Bradshaw, Larry S.; Fischer, William C. A computer system for scheduling fire use. Part 2—computer terminal operator's manual. Gen. Tech. Rep. INT-100. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1981b. 34 p.

Bratten, Frederick W.; Davis, James B.; Flatman, George T.; Keith, Jerold W; Rapp, Stanley R.; Storey, Theodore G. FOCUS: a fire management planning system - final report. Gen. Tech. Rep. PSW-49. Berkeley, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station; 1981. 34 p.

Deeming, John E.; Burgan, Robert E.; Cohen, Jack D. The National Fire-Danger Rating System—1978. Gen. Tech. Rep. INT-39. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1977. 63 p.

Furman, R. William. Using fire weather data in prescribed fire planning: two computer programs. Gen. Tech. Rep. RM-63. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station; 1979. 11 p.

Furman, R. William; Brink, Glen E. The National Fire Weather Library: what it is and how to use it. Gen. Tech. Rep. RM-19. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station; 1975. 8 p.

Gibson, James C. The frequency of favorable conditions for prescribed burning in the Black Hills. Fort Collins, CO: Colorado State University; 1977. Master's thesis.

Greenlee, John M. Wildland fire modeling and strategy assessment. Fire Technol. 18(3): 237-250; 1982.

Johnson, Von J.; Main, William A. A climatology of prescribed burning. In: Proceedings, fifth national conference on fire and forest meteorology; 1978 March 14-16; Atlantic City, NJ. Boston, MA: American Meteorological Society; 1978: 59-62.

Helfman, Robert S.; Straub, Robert J.; Deeming, John E. User's guide to AFFIRMS: time-sharing computerized processing for fire danger rating. Gen. Tech. Rep. INT-82. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1980. 150 p.

Main, William A.; Straub, Robert; Paananen, Donna M. FIREFAMILY: fire planning with historic weather data. Gen. Tech. Rep. NC-73. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station; 1982. 31 p.

Nelson, Thomas C. Fire management policy in the National Forests - a new era. J. For. 77(11): 723-725; 1979.

Yancik, Richard F.; Roussopoulos, Peter J. User's guide to the National Fire Occurrence Data Library. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station; 1982. 25 p.

APPENDIX A
RXBUILD Input Worksheets

Date ________ RXBUILD INPUT WORKSHEET

SHEET NO. 1 -- RUN IDENTIFICATION

1. TITLE. (Enter 1 to 80 characters.)

____

2. USER NAME. (Enter 1 to 80 characters.)

____

3. REGION NAME OR NUMBER. (Enter 1 to 80 characters.)

____

4. FOREST NAME. (Enter 1 to 80 characters.)

____

5. FOREST ADP CODE. __ __ __

6. NUMBER OF AFFIRMS WEATHER STATIONS TO BE USED IN THIS RUN.[1/] __ __ __

List of AFFIRMS stations to be used. List in order of increasing station number - smallest number first, largest number last.

6.__. ____________________ ____________________

6.__. ____________________ ____________________

6.__. ____________________ ____________________

6.__. ____________________ ____________________

6.__. ____________________ ____________________

6.__. ____________________ ____________________

[1/] Complete a separate Sheet No. 2 for each of the AFFIRMS stations listed in Item No. 6 above.

Page ____ of ____

Date ________

RXBUILD INPUT WORKSHEET

SHEET NO. 2 -- AFFIRMS STATION PARAMETERS

6.___. 6-DIGIT AFFIRMS STATION ID. _ _ _ _ _ _ _

6.___.1 AFFIRMS STATION NAME.[1] ____________________

6.___.2 AFFIRMS STATION ELEVATION. _ _ _ _ _ _

6.___.3 AFFIRMS STATION LATITUDE. _ _ _

6.___.4 NFDRS FUEL MODEL. _

6.___.5 NFDRS SLOPE CLASS. _ _

6.___.6 NFDRS HERBACEOUS TYPE. _

6.___.7 NFDRS CLIMATE CLASS. _ _

6.___.8 NFDRS GREENUP DATE. _ _ _ _ _

6.___.9 NFDRS FIRST FREEZE DATE. _ _ _ _ _

6.___.10 NFDRS WEEKDAY MAN RISK FACTOR. _ _ _ _

6.___.11 NFDRS WEEKEND MAN RISK FACTOR. _ _ _ _

6.___.12 NFDRS LIGHTNING SCALING FACTOR. _ _ _ _

6.___.13 NUMBER OF MANNING VARIABLES.[2] _ _

---

[1] 20 characters maximum.

[2] Complete Sheet No. 3 if Item No. 6.___.13 is greater than 0. A separate Sheet No. 3 must be completed for each AFFIRMS station indicated in Item 6, Sheet No. 1.

Page ____ of ____

Date __________ RXBUILD INPUT WORKSHEET

SHEET NO. 3 -- RUN IDENTIFICATION

AFFIRMS STATION NO. __ __ __ __ __ __

MANNING VARIABLE NO. 1

6.__.13.1.1 BASE VARIABLE FOR MANNING LEVEL. __ __ __

6.__.13.1.2 NO. OF MANNING LEVEL CLASSES. __ __ __

6.__.13.1.3 90th PERCENTILE VALUE OF BASE VARIABLE. __ __ __ __

6.__.13.1.4 97th PERCENTILE VALUE OF BASE VARIABLE. __ __ __ __

MANNING VARIABLE NO. 2

6.__.13.2.1 BASE VARIABLE FOR MANNING LEVEL. __ __ __

6.__.13.2.2 NO. OF MANNING LEVEL CLASSES. __ __ __

6.__.13.2.3 90th PERCENTILE VALUE OF BASE VARIABLE. __ __ __ __

6.__.13.2.4 97th PERCENTILE VALUE OF BASE VARIABLE. __ __ __ __

MANNING VARIABLE NO. 3

6.__.13.3.1 BASE VARIABLE FOR MANNING LEVEL. __ __ __

6.__.13.3.2 NO. OF MANNING LEVEL CLASSES. __ __ __

6.__.13.3.3 90th PERCENTILE VALUE OF BASE VARIABLE. __ __ __ __

6.__.13.3.4 97th PERCENTILE VALUE OF BASE VARIABLE. __ __ __ __

Page ___ of ___

Date ________

SHEET NO. 4 -- DATE PARAMETERS

7. BEGINNING YEAR. _ _ _

8. ENDING YEAR. _ _ _

9. BEGINNING SEASON DATE. _ _ _ _ _

10. ENDING SEASON DATE. _ _ _ _ _

11. NFWDL FILE NAME. _ _ _ _ _ _ _ _ _ _ _ _ _

12. NUMBER OF DISTRICTS.[1/] _ _ _

13. FIRE REPORT LISTING? _ _ _

14. WEATHER DATA FILE LISTING? _ _ _

[1/] Information on each District indicated here included on a Sheet No. 5, District Parameters.

Page ____ of ____

SHEET NO. 5 -- DISTRICT PARAMETERS

DISTRICT NO. ____

12.1.1 DISTRICT NAME. ______________________________

12.1.2 DISTRICT ADP CODE. __ __ __

12.1.3 DISTRICT AFFIRMS STATION. __ __ __

DISTRICT NO. ____

12.2.1 DISTRICT NAME. ______________________________

12.2.2 DISTRICT ADP CODE. __ __ __

12.2.3 DISTRICT AFFIRMS STATION. __ __ __

DISTRICT NO. ____

12.3.1 DISTRICT NAME. ______________________________

12.3.2 DISTRICT ADP CODE. __ __ __

12.3.3 DISTRICT AFFIRMS STATION. __ __ __

Page ____ of ____

APPENDIX B
RXFIRES Input Worksheets

Date ________

RXFIRES INPUT WORKSHEET

SHEET NO. 1 -- RUN IDENTIFICATION

1. RUN NAME.

____

2. USER NAME.

____

3. EXCLUSION CRITERIA. (Use Sheet No. 2)

4. FIRE SUPPRESSION CRITERIA. (Use Sheet No. 3)

5. OUTPUT LEVEL. __ __

5.1 INCHES OF PRECIPITATION. __ __ __ __

5.2 FIRE CASE HISTORY VARIABLES.

01.	02.	03.	04.	05.	06.	07.	08.	09.	10.	11.	12.
____	____	____	____	____	____	____	____	____	____	____	____

5.3 FIRE LOAD SUMMARY TABLE DATES.

First MMDD.	Last MMDD.	First YEAR.	Last YEAR.
____.	____.	____.	____.

Page ____ of ____

Date ________

SHEET NO. 2 -- FIRE EXCLUSION CRITERIA

EXCLUDE FIRES IF:

3.1 VARIABLE CODE	3.2 ARITHMETIC ARGUMENT	3.3 VALUE CODE	3.4 VARIABLE NAME	3.5 VARIABLE MEASURE
___ ___ ___	___ ___	___ ___ ___ ___ ___.	____________	________
___ ___ ___	___ ___	___ ___ ___ ___ ___.	____________	________
___ ___ ___	___ ___	___ ___ ___ ___ ___.	____________	________
___ ___ ___	___ ___	___ ___ ___ ___ ___.	____________	________
___ ___ ___	___ ___	___ ___ ___ ___ ___.	____________	________
___ ___ ___	___ ___	___ ___ ___ ___ ___.	____________	________
___ ___ ___	___ ___	___ ___ ___ ___ ___.	____________	________
___ ___ ___	___ ___	___ ___ ___ ___ ___.	____________	________
___ ___ ___	___ ___	___ ___ ___ ___ ___.	____________	________
___ ___ ___	___ ___	___ ___ ___ ___ ___.	____________	________
___ ___ ___	___ ___	___ ___ ___ ___ ___.	____________	________
___ ___ ___	___ ___	___ ___ ___ ___ ___.	____________	________
___ ___ ___	___ ___	___ ___ ___ ___ ___.	____________	________
___ ___ ___	___ ___	___ ___ ___ ___ ___.	____________	________
___ ___ ___	___ ___	___ ___ ___ ___ ___.	____________	________
___ ___ ___	___ ___	___ ___ ___ ___ ___.	____________	________
___ ___ ___	___ ___	___ ___ ___ ___ ___.	____________	________
___ ___ ___	___ ___	___ ___ ___ ___ ___.	____________	________
___ ___ ___	___ ___	___ ___ ___ ___ ___.	____________	________
___ ___ ___	___ ___	___ ___ ___ ___ ___.	____________	________
___ ___ ___	___ ___	___ ___ ___ ___ ___.	____________	________

Page ____ of ____

Date ________

RXFIRES INPUT WORKSHEET

SHEET NO. 3 -- FIRE SUPPRESSION CRITERIA

SUPPRESS FIRES IF:

4.1 VARIABLE CODE	4.2 ARITHMETIC ARGUMENT	4.3 VALUE CODE	4.4 PREVIEW DAYS	4.5 VARIABLE NAME	4.6 VARIABLE MEASURE
___ ___ ___	___ ___	___ ___ ___ ___ ___.	___ ___ ___	____________	________
___ ___ ___	___ ___	___ ___ ___ ___ ___.	___ ___ ___	____________	________
___ ___ ___	___ ___	___ ___ ___ ___ ___.	___ ___ ___	____________	________
___ ___ ___	___ ___	___ ___ ___ ___ ___.	___ ___ ___	____________	________
___ ___ ___	___ ___	___ ___ ___ ___ ___.	___ ___ ___	____________	________
___ ___ ___	___ ___	___ ___ ___ ___ ___.	___ ___ ___	____________	________
___ ___ ___	___ ___	___ ___ ___ ___ ___.	___ ___ ___	____________	________
___ ___ ___	___ ___	___ ___ ___ ___ ___.	___ ___ ___	____________	________
___ ___ ___	___ ___	___ ___ ___ ___ ___.	___ ___ ___	____________	________
___ ___ ___	___ ___	___ ___ ___ ___ ___.	___ ___ ___	____________	________
___ ___ ___	___ ___	___ ___ ___ ___ ___.	___ ___ ___	____________	________
___ ___ ___	___ ___	___ ___ ___ ___ ___.	___ ___ ___	____________	________
___ ___ ___	___ ___	___ ___ ___ ___ ___.	___ ___ ___	____________	________
___ ___ ___	___ ___	___ ___ ___ ___ ___.	___ ___ ___	____________	________
___ ___ ___	___ ___	___ ___ ___ ___ ___.	___ ___ ___	____________	________
___ ___ ___	___ ___	___ ___ ___ ___ ___.	___ ___ ___	____________	________
___ ___ ___	___ ___	___ ___ ___ ___ ___.	___ ___ ___	____________	________
___ ___ ___	___ ___	___ ___ ___ ___ ___.	___ ___ ___	____________	________
___ ___ ___	___ ___	___ ___ ___ ___ ___.	___ ___ ___	____________	________
___ ___ ___	___ ___	___ ___ ___ ___ ___.	___ ___ ___	____________	________

Page ____ of ____

U.S. GOVERNMENT PRINTING OFFICE: 1983—776-032/1041 REGION NO. 8

Bevins, Collin D.; Fischer, William C. A computer system for testing fire management prescriptions: part 1—user's manual. Gen. Tech. Rep. INT-155. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1983. 42 p.

Describes a user-oriented computer system that allows fire managers to evaluate alternative prescriptions for unscheduled prescribed fires within specific fire management planning areas. Provides instructions for the use of the system, preparation of appropriate program inputs, and obtaining program output. Part 2—Computer Terminal Operator's Manual (Bevins and Fischer 1983) is available as a separate general technical report.

KEYWORDS: prescribed fire, fire management, fire management planning, land management planning, computer systems

The Intermountain Station, headquartered in Ogden, Utah, is one of eight regional experiment stations charged with providing scientific knowledge to help resource managers meet human needs and protect forest and range ecosystems.

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**Intermountain
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Ogden, UT 84401**

General Technical
Report INT-156

October 1983

A Computer System for Testing Fire Management Prescriptions:

Part 2—Computer Terminal Operator's Manual

Collin D. Bevins
William C. Fischer

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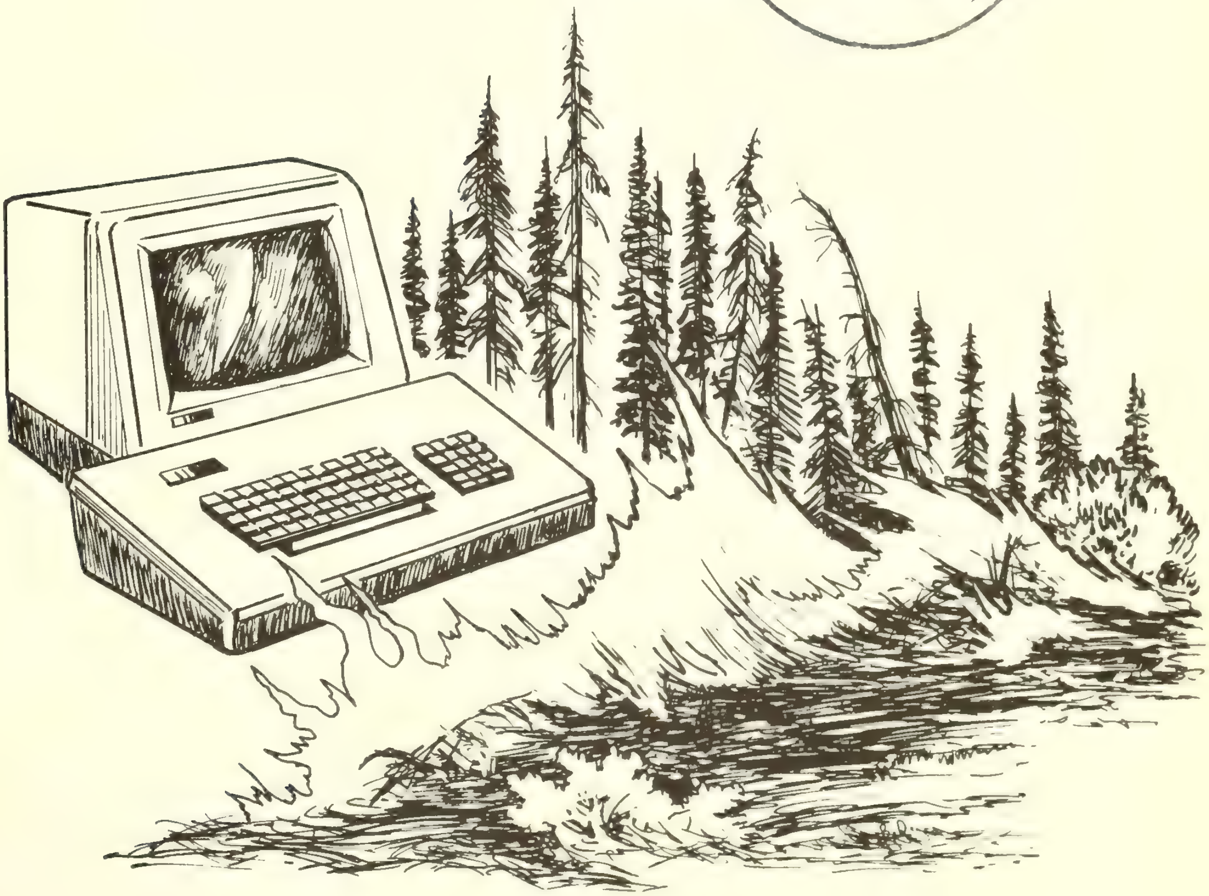

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RESEARCH SUMMARY

This report outlines the structure of a user-oriented computer system that allows fire managers to examine computerized historical fire-occurrence and weather records and identify ignitions that would have qualified as prescribed fires according to the conditions of a test prescription. Qualifying fires are "allowed to burn" under prevailing weather conditions until extinguished by precipitation or until they burn out of prescription. Test prescription parameters may include up to 60 fire-occurrence, fire-weather, fire-danger, and fire-manning-level variables.

Instructions for data entry and program execution are provided. Sample output demonstrates successful program execution. A companion report, Part 1—User's Guide (Bevins and Fischer 1983), is available as a separate general technical report.

A Computer System for Testing Fire Management Prescriptions:

Part 2—Computer Terminal Operator's Manual

Collin D. Bevins
William C. Fischer

INTRODUCTION

The purpose of this report is to facilitate use of programs RXBUILD and RXFIRES. These programs provide information that can be used to evaluate alternative prescriptions for unscheduled prescribed fires within specific fire management planning areas. The programs examine historical fire-occurrence and weather records and identify ignitions that would have qualified as prescribed fires according to the conditions of a test prescription. Qualifying fires are "allowed to burn" under prevailing weather conditions until extinguished by precipitation or until they exceed prescribed conditions.

Program RXBUILD collates the necessary fire-occurrence and fire- weather data from computer archives and creates a data set specific to a fire management area. The data set may be printed at the user's request.

Program RXFIRES reads the user's test prescription and checks each historical fire for compliance. A table of unscheduled prescribed fires and wildfires by year and size class is printed. The user may also request a case history of each unscheduled prescribed fire and a fire load summary table. RXFIRES may be used repeatedly to test alternative prescriptions for a single fire management area data set created by program RXBUILD.

Programs RXBUILD and RXFIRES are written in ASCII 3.9X-77 FORTRAN and are available on the Region 1 shared library CSSG*R1LIB, USDA Forest Service, Fort Collins Computer Center, Fort Collins, Colo.

SYSTEM STRUCTURE AND OPERATION

The steps necessary to successfully operate RXFIRES are shown in table 1. The left-hand column identifies the steps usually performed by the fire management officer, fire planner, or other user of program output. This person is primarily concerned with selecting appropriate program inputs and interpreting program outputs. A companion report, Part 1—User's Manual (Bevins and Fischer 1983), provides instructions to these users.

The right-hand column of table 1 identifies the steps that are usually performed by the terminal operator or computer specialist who enters the data, submits the programs for execution, and maintains the data files. This report contains detailed instructions for those steps.

Programs RXBUILD and RXFIRES each consist of two executable elements:

CSSG*R1LIB.RXBUILD and CSSG*R1LIB.RXBUILD2
CSSG*R1LIB.RXFIRES and CSSG*R1LIB.RXFIRES2

Table 1.—List of steps necessary to operate programs RXBUILD and RXFIRES

Fire planner responsibilities	Terminal operator responsibilities
PROGRAM RXBUILD	
1. Complete RXBUILD input worksheet.	
	2. Determine NFWDL tape name. (Consult Furman and Brink 1975)
	3. Create NFODL SPSS-style fire file. (Consult Vancik and Roussopoules 1982).
	4. Access CSSG*R1LIB.RXBUILD to enter worksheet items and create an input directive file.
	5. @ADD the RXBUILD directive file to execute CSSG*R1LIB.RXBUILD2.
6. Interpret RXBUILD output.	
PROGRAM RXFIRES	
7. Complete RXFIRES input worksheet.	
	8. Access CSSG*R1LIB.RXFIRES to enter worksheet items and create an input directive file.
	9 @ADD the RXFIRES directive file to execute CSSG*R1LIB.RXFIRES2.
10. Interpret RXFIRES output.	
11. Return to step 7 for next test prescription.	

Executable elements RXBUILD and RXFIRES are interactive routines that prompt the terminal operator for items from the RXBUILD and RXFIRES input worksheets, respectively. They test each entry for value-range and decimal point. If errors are detected, a diagnostic message is printed to the terminal and the item can then be reentered correctly. Both routines write the edited entries and additional Exec 8 control statements to an output file on logical unit 7. The output files become the input directive files for executable elements RXBUILD2 and RXFIRES2.

Executable elements RXBUILD2 and RXFIRES2 are batch routines initiated by @ADDing the respective input directive files created by RXBUILD and RXFIRES.

The interaction between users, executable elements, and input and output files is shown in figure 1. A list of the 60 variables that can be used as prescription parameters in programs RXBUILD and RXFIRES is contained in table 2.

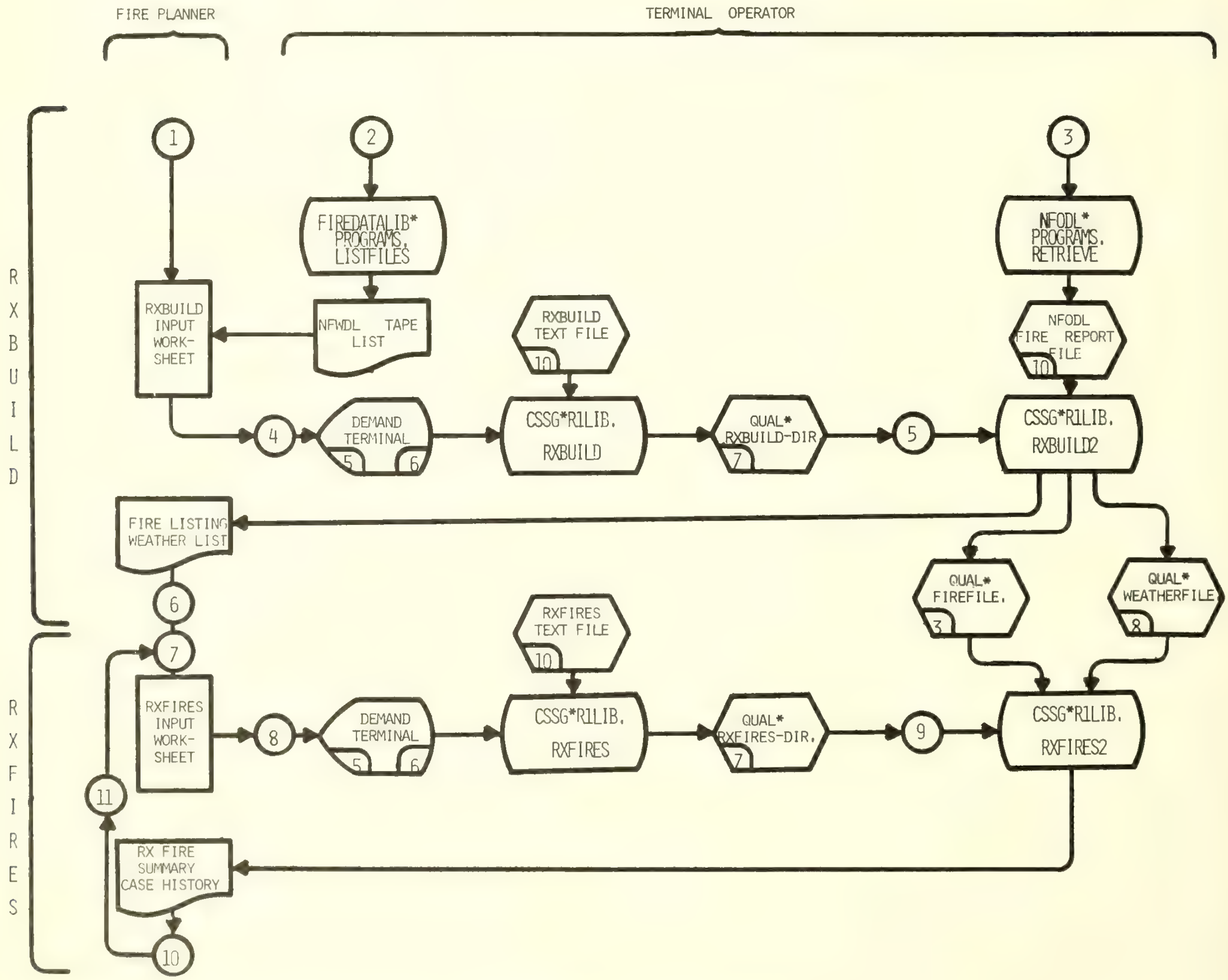


Figure 1.—Structure and operational routine for programs RXBUILD and RXFIRES.

Table 2.—List of variables that can be used as prescription parameters; programs RXBUILD and RXFIRES

Variable code	Variable name	Variable value code and unit of measure
1	Agency	1 = USDA Forest Service
2	Region	1 = R1, 2 = R2, ..., 0 = R10
3	Administering National Forest	Coded; consult FSH 5109-14
4	District	Coded; consult FSH 5109-14
5	Reporting National Forest	Coded; consult FSH 5109-14
6	Jurisdiction at origin	Coded; consult FSH 5109-14
7	State	Coded; consult FSH 5109-14
8	County	Coded; consult FSH 5109-14
9	Watershed	Coded; consult FSH 5109-14
10	Supervisor's fire number	
11	Year of origin	70 = 1970, 81 = 1981
12	Month of origin	1 = Jan, 2 = Feb, ..., 12 = Dec
13	Date of origin	0101 = Jan 1, 0615 = Jun 15, 1231 = Dec 31
14	Day of week of origin	1 = Sun, 2 = Mon, ..., 7 = Sat
15	Statistical cause	Coded; consult FSH 5109-14
16	General cause	Coded; consult FSH 5109-14
17	Specific cause	Coded; consult FSH 5109-14
18	Fire size class	1 = A, 2 = B, ..., 7 = G
19	Acres burned	Actual value; nearest whole acre
20	Individuals who started fire	Coded; consult FSH 5109-14
21	Hour of fire origin	Nearest hour, 24-hour clock time
22	Total hours to control	Actual value; nearest whole hour
23	Max. - suppression personnel	Actual number
24	Slope class	Coded; consult FSH 5109.14
25	Aspect class	Coded; consult FSH 5109.14
26	Elevation class	Coded; consult FSH 5109.14
27	Topography class	Coded; consult FSH 5109.14
28	Cover type at origin	Coded; consult FSH 5109.14
29	Fuel type at origin	Coded; consult FSH 5109.14
30	Fuel type prevailing	Coded; consult FSH 5109.14
31	State of the weather	Coded; consult FSH 5109.14
32	Temperature	Actual value; nearest whole °F
33	Relative humidity	Actual value; nearest whole percent
34	Wind direction	Coded; consult Deeming and others (1977)
35	Windspeed per hour	Actual value; nearest whole mile
36	Maximum temperature	Actual value; nearest whole °F
37	Minimum temperature	Actual value; nearest whole °F
38	Maximum relative humidity	Actual value; nearest whole percent
39	Minimum relative humidity	Actual value; nearest whole percent
40	Precipitation duration	Actual value; nearest whole hour
41	Precipitation trace	1 = trace, 0 = none
42	Precipitation amount	Actual value; nearest 100th of an inch
43	Lightning activity level	Coded
44	Man-caused risk	Actual value; nearest 100th
45	1-hour fuel moisture	Actual value; nearest 10th percent
46	10-hour fuel moisture	Actual value; nearest 10th percent
47	100-hour fuel moisture	Actual value; nearest 10th percent
48	1000-hour fuel moisture	Actual value; nearest 10th percent
49	Live woody fuel moisture	Actual value; nearest whole percent
50	Live herbaceous fuel moisture	Actual value; nearest whole percent
51	Ignition component	Actual value
52	Spread component	Actual value
53	Energy release component	Actual value
54	Person-caused occurrence index	Actual value
55	Lightning occurrence index	Actual value
56	Burning index	Actual value
57	Fire load index	Actual value
58	Manning level variable 1	Coded; user defined
59	Manning level variable 2	Coded; user defined
60	Manning level variable 3	Coded; user defined

---

[1] USDA Forest Service, Individual Fire Report Handbook, Form 5100-29

INITIAL DATA ENTRY

Obtain Fire Weather Data Tape Name

Program RXBUILD retrieves archived AFFIRMS weather observations from the National Fire Weather Data Library (NFWDL) (Furman and Brink 1975). The data are stored on magnetic tape by AFFIRMS station 6-digit ID number and year. It is necessary to supply RXBUILD with the name of the tape containing data for the first year of the lowest numbered AFFIRMS station (step 2, table 1 and fig. 1). The following run stream will produce a one-page listing of the AFFIRMS data tapes:

```
0        1         2         3         4
1234567890123456789012345678901234567890
@RUN, . . .
@ASG,A FIREDATALIB*PROGRAMS.
@XQT    FIREDATALIB*PROGRAMS.LISTFILES
@FIN
```

Output from the run sequence is shown in exhibit 1. Tape qualifier and file names are in the left column. The station-year limits are in format "sssssyy", where "ssssss" is the 6-digit AFFIRMS station number and "yy" is the last two digits of the year.

Data for AFFIRMS station 240112 beginning in 1970 (e.g., "STATION-YEAR LIMITS" of 24011270), for example, are stored on tape FIREDATALIB* 21-24. RXBUILD must be supplied with the file name portion only, or "21-24.".

Caution: Tape names and station-year limits are updated periodically. Consult Furman and Brink (1975) for a more complete discussion of the NFWDL.

Create a Fire Report File

Program RXBUILD reads fire report records generated by the National Fire Occurrence Data Library (NFODL) program NFODL*PROGRAMS.RETRIEVE (Yancik and Roussopoulos 1982). The following run stream will create a file of fire reports from 1970 through 1980 for Forest 14, Region 1 (step 3, table 1, and fig. 1):

```
0        1         2         3         4
1234567890123456789012345678901234567890
@RUN,
@ASG,A NFODL*PROGRAMS.
@XQT    NFODL*PROGRAMS.NFO-RETRIEVE
USAGE SPSS
REGION 01
FOREST 14 1970-1980
@EOF
@FIN
```

Program NFO-RETRIEVE dynamically creates a mass storage data file of the retrieved historical fire-occurrence records. The files are available for 6 calendar days from the time of initial creation unless @SAVE'd for a longer period. The name of the newly created fire file has the format:

NFOrrffSPSS*mmddyyhhmmss

where "rr" is the Region number, "ff" is the Forest number, "mmddyy" is the month, day, and year the file was created, and "hhmmss" is the hour, minute, and second of file creation.

```
                      STATION-YEAR LIMITS    DATE OF
FILE                  FROM       THROUGH    LAST UPDATE

FIREDATALIB*00-03     00000000   03999999     030283
FIREDATALIB*04        04000000   04079999     030283
FIREDATALIB*04A       04080000   04329999     030283
FIREDATALIB*04B       04330000   04510599     030283
FIREDATALIB*04C       04510600   04999999     030283
FIREDATALIB*05-09     05000000   09999999     030283
FIREDATALIB*10        10000000   10109999     030283
FIREDATALIB*10A-20    10110000   20999999     030283
FIREDATALIB*21-24     21000000   24179999     030283
FIREDATALIB*24A-26    24180000   26999999     030283
FIREDATALIB*27-35     27000000   35239999     030283
FIREDATALIB*35A-41    35240000   41999999     030283
FIREDATALIB*42-45     42000000   45169999     030283
FIREDATALIB*45A-47    45170000   47999999     030283
FIREDATALIB*48-50     48000000   50999999     030283
FIREDATALIB*NEWYR     00000000   99999999     062083
FIREDATALIB*FRCST     00000000   99999999     062083
FIREDATALIB*FSTALL    00000000   99999999     030283

NOTE - THE TIME LAG IN THE RECORDING OF THE LIGHTNING ACTIVITY LEVEL
 HAS BEEN REMOVED FROM THE DATA IN THE REGULAR LIBRARY, BUT IS STILL
 PRESENT IN THE NEW DATA BEING COLLECTED (NEWDAT).  IT WILL BE
 REMOVED WHEN THAT DATA IS MERGED INTO THE REGULAR LIBRARY.
```

Exhibit 1.—Sample program FIREDATALIB*PROGRAMS.LISTFILES output.

To obtain further documentation of the NFODL, use the following run stream:

```
Image  0         1         2         3         4
 No.   1234567890123456789012345678901234567890
  1    @RUN,...
  2    @ASG,A NFODL*INFORMATION
  3    @PRT,S NFODL*INFORMATION.RETRIEVE
  4    @PRT,S NFODL*INFORMATION.VARIABLES
  5    @PRT,S NFODL*INFORMATION.CODES
  6    @FIN
```

PROGRAM RXBUILD

RXBUILD Initiation

Use program CSSG*R1LIB.RXBUILD to enter items from the RXBUILD input worksheet to a DEMAND terminal. A file (qual*rxbuild-dir.) must be assigned to logical unit 7 to hold the directives written by RXBUILD. The following run stream is used to initiate CSSG*R1LIB.RXBUILD interactive processing at a DEMAND terminal (step 4, table 1, and fig. 1):

```
Image  0         1         2         3         4
 No.   1234567890123456789012345678901234567890
  1    @RUN,...
  2    @ASG,A CSSG*R1LIB
  3    @ASG,UP qual*rxbuild-dir.
  4    @USE 7.,qual*rxbuild-dir.
  5    @XQT     CSSG*R1LIB.RXBUILD
```

All items entered from the RXBUILD worksheet into the terminal are edited and written onto the RXBUILD directive file named "qual*rxbuild-dir.".

RXBUILD Data Entry

RXBUILD first asks the terminal operator whether an introduction is to be printed. The introduction contains one screen (24 lines) of program description, one screen of input rules, and one screen of interactive program initiation information. RXBUILD then asks if an update is to be printed, and prints the date of the last update. The update will contain new information concerning RXBUILD and RXFIRES use.

RXBUILD then prompts the terminal operator for all items from the RXBUILD input worksheet. The following input rules apply:

1. All numeric entries must contain a decimal point. Failure to include the decimal will cause an error diagnostic to be printed to the terminal. The operator then has another chance to correctly reenter the data.
2. Entries may be made beginning in the left-most column.
3. Program execution may be terminated at any time by entering "STOP", beginning in the left-most column (it may be necessary to enter "STOP" twice successively). The program will terminate without writing a directive file on logical unit 7.

All entries are checked for value-range and decimal point. Self-explanatory error diagnostics are printed to the terminal if data entries are out of range or do not have a decimal point. The operator will be given another chance to correctly reenter the data or "STOP".

After all input items have been correctly entered, RXBUILD asks the operator whether to print directions on submitting the output directive file for CSSG*R1LIB.RXBUILD2 processing. The instructions contain two screens of information on file assignments and run streams. This information is discussed in the following pages.

A sample RXBUILD input session is shown in exhibit 2 for the Cabinet Wilderness fire management plan. The data were entered from the sample RXBUILD input worksheets shown in exhibit 3. Detailed instructions for completing RXBUILD input worksheets are given in the User's Guide (Bevins and Fischer 1983).

```
@ASG,A  CSSG*R1LIB.
FACILIT  WARNING  000200100000
 @ASG,CP QUALIFIER*RXBUILD-DIR.
READ:
>@USE 7.,QUALIFIER*RXBUILD-DIR.
READ:
 @XQT     CSSG*R1LIB.RXBUILD



BEGIN CSSG*R1LIB.RXBUILD             DATE:062283    TIME:105437




ENTER "YES" IF YOU WANT AN INTRODUCTION.
>YES


PROGRAM          CSSG*R1LIB.RXBUILD

LANGUAGE         ASCII 3.9X-77 FORTRAN

MACHINE          UNIVAC 1100/84

USAGE            INTERACTIVE DEMAND (80 CHARACTERS)

PROGRAMMED       COLLIN D. BEVINS
                 SYSTEMS FOR ENVIRONMENTAL MANAGEMENT
                 P.O. BOX 3776
                 MISSOULA, MONTANA  59806
                 (406) 549-7478

REFERENCE        BEVINS,C.D., AND W.C. FISCHER.  1982.
                 A COMPUTER SYSTEM FOR TESTING FIRE MANAGEMENT
                 PRESCRIPTIONS, PART II: TERMINAL OPERATORS' MANUAL.
                 USDA FOREST SERVICE GEN. TECH. REP. INT-    .
                 INTERMTN. FOREST & RANGE EXPT. STN., OGDEN, UT. 84401

HIT CARRIAGE RETURN TO CONTINUE.
>

                          *************
                             ESCAPE!
                          *************

IF YOU WISH TO TERMINATE THIS PROGRAM AT ANY TIME,
ENTER THE COMMAND 'STOP' FOLLOWED BY A CARRIAGE RETURN.


                     *****************
                        INPUT RULES
                     *****************


1.  ALL INFORMATION MUST BE ENTERED BEGINNING IN COLUMN 1 .

2.  ALL NUMERIC DATA MUST INCLUDE A DECIMAL POINT .
    (TO BE SAFE, TERMINATE ALL INPUT WITH A DECIMAL POINT.)




HIT CARRIAGE RETURN TO CONTINUE.
>
                  **************************
                     CATALOG YOUR OUTPUT!
                  **************************

CSSG*R1LIB.RXBUILD IS AN INTERACTIVE PROGRAM THAT ASKS YOU
FOR INFORMATION REQUIRED TO BUILD A FIRE REPORT AND WEATHER
DATA FILE FOR SELECTED DISTRICTS ON A NATIONAL FOREST.

THE PROGRAM READS EACH PIECE OF INFORMATION ENTERED, CHECKS IT
FOR OBVIOUS ERRORS, AND WRITES IT TO AN OUTPUT FILE ON UNIT 7
FOR YOUR LATER USE.  YOU MUST HAVE @ASG'D AND @USE'D A FILE TO HOLD
THE PROGRAM OUTPUT ON LU 7 OR IT WILL DISAPPEAR AT @FIN TIME.

THE FOLLOWING RUN STREAM SHOULD BE USED:

1. @RUN,...
2. @ASG,A  CSSG*R1LIB.
3. @ASG,CP (YOUR QUALIFIER*FILENAME)
4. @USE 7.,(YOUR QUALIFIER*FILENAME).
5. @XQT     CSSG*R1LIB.RXBUILD

IF YOU DID NOT FOLLOW THE ABOVE PROCEDURE, ENTER 'STOP'
AND TRY AGAIN.  ENTER CARRIAGE RETURN TO CONTINUE.
>




ENTER "YES" IF YOU WANT THE LATEST UPDATE (03/01/82).
>YES
                              ************
                                 UPDATE
                              ************

NO UPDATES OR ADDITIONS TO USERS' OR TERMINAL OPERATORS' MANUALS.
```

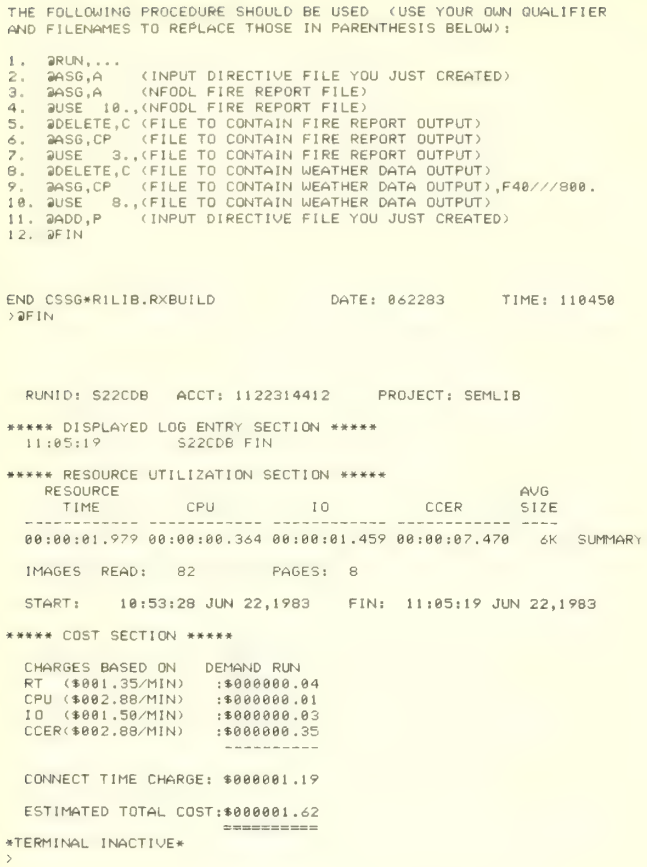
```
HIT CARRIAGE RETURN TO CONTINUE
>
1.  TITLE.
    ENTER 1 TO 80 CHARACTERS.
>CABINET WILDERNESS AREA FIRE MANAGEMENT PLAN
2.  USER NAME.
    ENTER 1 TO 80 CHARACTERS.
>JOSEPH M. GLASSY
3.  REGION NAME OR NUMBER.
    ENTER 1 TO 80 CHARACTERS.
>NORTHERN REGION (R01)
4.  FOREST NAME.
    ENTER 1 TO 80 CHARACTERS.
>KOOTENAI NATIONAL FOREST (F14)
5.  FOREST ADP CODE.
    ENTER FOREST ADP CODE FROM 1. TO 30.
    INCLUDE THE DECIMAL POINT.
>14.
6.  NUMBER OF AFFIRMS WEATHER STATIONS.
    ENTER FROM 1. TO 10. STATIONS.
    INCLUDE THE DECIMAL POINT.
>2.
6. 1.  6-DIGIT ID OF AFFIRMS STATION NO.  1
       ENTER 6-DIGIT ID OF LOWEST NUMBERED AFFIRMS STATION.
       REMEMBER THE DECIMAL POINT!
>240112.
6. 1.1.  AFFIRMS STATION NAME.
         ENTER 1 TO 20 CHARACTERS.
>TROY RD AFFIRMS
6. 1.2.  AFFIRMS STATION ELEVATION.
         ENTER THE ELEVATION BETWEEN 0. AND 12000. FEET.
         INCLUDE THE DECIMAL POINT.
>1950.
6. 1.3.  AFFIRMS STATION LATITUDE.
         ENTER LATITUDE IN DEGREES.
         INCLUDE THE DECIMAL POINT.
>48.
6. 1.4.  NFDRS FUEL MODEL.
         ENTER LETTER A THROUGH U (EXCEPT M).
>G
6. 1.5.  NFDRS SLOPE CLASS.
         ENTER SLOPE CLASS 1. THROUGH 5.
         INCLUDE THE DECIMAL POINT.
>3.
6. 1.6.  NFDRS HERBACEOUS TYPE.
         ENTER LETTER P (PERENNIAL) OR LETTER A (ANNUAL).
>P

6. 1.7.  NFDRS CLIMATE CLASS.
         ENTER CLIMATE CLASS 1. THROUGH 4.
         INCLUDE THE DECIMAL POINT.
>3.
6. 1.8.  NFDRS GREENUP DATE.
         ENTER MONTH AND DAY OF YEARLY GREENUP
         FOR EXAMPLE, ENTER MAY 15 AS "0515.".
>601.
6. 1.9.  NFDRS FIRST FREEZE DATE.
         ENTER MONTH AND DAY OF FIRST ANNUAL FREEZE
         FOR EXAMPLE, ENTER SEPT 1 AS "0901.".
>915.
6. 1.10.  NFDRS WEEKDAY MAN RISK FACTOR.
          ENTER WEEKDAY MAN RISK FACTOR BETWEEN 0. AND 100.
          INCLUDE THE DECIMAL POINT.
>1.
6. 1.11.  NFDRS WEEKEND MAN RISK FACTOR.
          ENTER WEEKEND MAN RISK FACTOR BETWEEN 0. AND 100.
          INCLUDE THE DECIMAL POINT.
>1.
6. 1.12.  NFDRS LIGHTNING SCALING FACTOR.
          ENTER LIGHTNING FACTOR BETWEEN 0. AND 100.
          INCLUDE THE DECIMAL POINT.
>1.
6. 1.13.  NO. MANNING VARIABLES.
          ENTER 0. TO 3. MANNING VARIABLES TO BE DEFINED.
          INCLUDE THE DECIMAL POINT.
>2.
6. 1.13.1.1.  BASE VARIABLE FOR MANNING VARIABLE NO. 58.
              ENTER CODE OF VARIABLE USED IN
              COMPUTING THE MANNING VAR. NO.
              ENTER BASE VARIABLE CODE 31. TO 57.
              INCLUDE THE DECIMAL POINT.
>53.
6. 1.13.1.2.  NO. CLASSES OF MANNING VARIABLE NO. 58.
              ENTER FROM 4. TO 10. CLASSES.
              INCLUDE THE DECIMAL POINT.
>5.
6. 1.13.1.3.  90TH PERCENTILE VALUE OF BASE VARIABLE NO. 53.
              ENTER 90TH PERCENTILE VALUE.
              INCLUDE THE DECIMAL POINT.
>62.
6. 1.13.1.4.  97TH PERCENTILE VALUE OF BASE VARIABLE NO. 53.
              ENTER 97TH PERCENTILE VALUE.
              INCLUDE THE DECIMAL POINT.
>69.
6. 1.13.2.1.  BASE VARIABLE FOR MANNING VARIABLE NO. 59.
              ENTER CODE OF VARIABLE USED IN
              COMPUTING THE MANNING VAR. NO.
              ENTER BASE VARIABLE CODE 31. TO 58.
              INCLUDE THE DECIMAL POINT.
>56.
6. 1.13.2.2.  NO. CLASSES OF MANNING VARIABLE NO. 59.
              ENTER FROM 4. TO 10. CLASSES.
              INCLUDE THE DECIMAL POINT.
>5.
```

(con.)

Exhibit 2.—Sample program RXBUILD data entry session.

```
6. 1.13.2.3.  90TH PERCENTILE VALUE OF BASE VARIABLE NO. 56.
              ENTER 90TH PERCENTILE VALUE.
              INCLUDE THE DECIMAL POINT.
>59.
6. 1.13.2.4.  97TH PERCENTILE VALUE OF BASE VARIABLE NO. 56.
              ENTER 97TH PERCENTILE VALUE.
              INCLUDE THE DECIMAL POINT.
>68.
6. 2.  6-DIGIT ID OF AFFIRMS STATION NO.  2
       ENTER 6-DIGIT ID OF NEXT LOWEST AFFIRMS STATION.
       REMEMBER THE DECIMAL POINT!
>240116.
6. 2.1.  AFFIRMS STATION NAME.
         ENTER 1 TO 20 CHARACTERS.
>BIG SWEDE MTN.
6. 2.2.  AFFIRMS STATION ELEVATION.
         ENTER THE ELEVATION BETWEEN 0. AND 12000. FEET.
         INCLUDE THE DECIMAL POINT.
>4336.
6. 2.3.  AFFIRMS STATION LATITUDE.
         ENTER LATITUDE IN DEGREES.
         INCLUDE THE DECIMAL POINT.
>48.
6. 2.4.  NFDRS FUEL MODEL.
         ENTER LETTER A THROUGH U (EXCEPT M).
>G
6. 2.5.  NFDRS SLOPE CLASS.
         ENTER SLOPE CLASS 1. THROUGH 5.
         INCLUDE THE DECIMAL POINT.
>3.
6. 2.6.  NFDRS HERBACEOUS TYPE.
         ENTER LETTER P (PERENNIAL) OR LETTER A (ANNUAL).
>P
6. 2.7.  NFDRS CLIMATE CLASS.
         ENTER CLIMATE CLASS 1. THROUGH 4.
         INCLUDE THE DECIMAL POINT.
>3.
6. 2.8.  NFDRS GREENUP DATE.
         ENTER MONTH AND DAY OF YEARLY GREENUP
         FOR EXAMPLE, ENTER MAY 15 AS "0515.".
>601.
6. 2.9.  NFDRS FIRST FREEZE DATE.
         ENTER MONTH AND DAY OF FIRST ANNUAL FREEZE
         FOR EXAMPLE, ENTER SEPT 1 AS "0901.".
>915.
6. 2.10.  NFDRS WEEKDAY MAN RISK FACTOR.
          ENTER WEEKDAY MAN RISK FACTOR BETWEEN 0. AND 100.
          INCLUDE THE DECIMAL POINT.
>1.
6. 2.11.  NFDRS WEEKEND MAN RISK FACTOR.
          ENTER WEEKEND MAN RISK FACTOR BETWEEN 0. AND 100.
          INCLUDE THE DECIMAL POINT.
>1.
6. 2.12.  NFDRS LIGHTNING SCALING FACTOR.
          ENTER LIGHTNING FACTOR BETWEEN 0. AND 100.
          INCLUDE THE DECIMAL POINT.
>1.
6. 2.13.  NO. MANNING VARIABLES.
          ENTER 0. TO 3. MANNING VARIABLES TO BE DEFINED.
          INCLUDE THE DECIMAL POINT.
>2.
6. 2.13.1.1.  BASE VARIABLE FOR MANNING VARIABLE NO. 58.
              ENTER CODE OF VARIABLE USED IN
              COMPUTING THE MANNING VAR. NO.
              ENTER BASE VARIABLE CODE 31. TO 57.
              INCLUDE THE DECIMAL POINT.
>53.
6. 2.13.1.2.  NO. CLASSES OF MANNING VARIABLE NO. 58.
              ENTER FROM 4. TO 10. CLASSES.
              INCLUDE THE DECIMAL POINT.
>5.
6. 2.13.1.3.  90TH PERCENTILE VALUE OF BASE VARIABLE NO. 53.
              ENTER 90TH PERCENTILE VALUE.
              INCLUDE THE DECIMAL POINT.
>62.
6. 2.13.1.4.  97TH PERCENTILE VALUE OF BASE VARIABLE NO. 53.
              ENTER 97TH PERCENTILE VALUE.
              INCLUDE THE DECIMAL POINT.
>69.
6. 2.13.2.1.  BASE VARIABLE FOR MANNING VARIABLE NO. 59.
              ENTER CODE OF VARIABLE USED IN
              COMPUTING THE MANNING VAR. NO.
              ENTER BASE VARIABLE CODE 31. TO 58.
              INCLUDE THE DECIMAL POINT.
>56.
6. 2.13.2.2.  NO. CLASSES OF MANNING VARIABLE NO. 59.
              ENTER FROM 4. TO 10. CLASSES.
              INCLUDE THE DECIMAL POINT.
>5.
6. 2.13.2.3.  90TH PERCENTILE VALUE OF BASE VARIABLE NO. 56.
              ENTER 90TH PERCENTILE VALUE.
              INCLUDE THE DECIMAL POINT.
>59.
6. 2.13.2.4.  97TH PERCENTILE VALUE OF BASE VARIABLE NO. 56.
              ENTER 97TH PERCENTILE VALUE.
              INCLUDE THE DECIMAL POINT.
>68.
7.  BEGINNING YEAR.
    FIRST YEAR OF FIRE REPORTS AND WEATHER DATA TO BE USED.
    ENTER LAST 2 DIGITS AND INCLUDE THE DECIMAL POINT.
>70.
8.  ENDING YEAR.
    LAST YEAR OF FIRE REPORTS AND WEATHER DATA TO BE USED.
    ENTER LAST 2 DIGITS AND INCLUDE THE DECIMAL POINT.
>80.
9.  BEGINNING SEASON DATE.
    FIRST MONTH AND DAY OF FIRE AND WEATHER DATA TO BE USED.
         ENTER IN MMDD FORMAT INCLUDE DECIMAL POINT.
         FOR EXAMPLE, ENTER MAY 15 AS "0515.".
>101.
10.  ENDING SEASON DATE.
     LAST MONTH AND DAY OF FIRE AND WEATHER DATA TO BE USED.

         ENTER IN MMDD FORMAT INCLUDE DECIMAL POINT.
         FOR EXAMPLE, ENTER SEPT 1 AS "0901.".
>1231.
11.  NFWDL FILE NAME.
     ENTER NAME OF NFWDL FILE CONTAINING STATION YEAR LIMITS OF 24011270.
     ENTER FILENAME AND TERMINATE WITH A PERIOD.
>21-24.
12.  NUMBER OF DISTRICTS.
     ENTER FROM 1. TO 10. DISTRICTS WHOSE FIRE REPORTS ARE TO BE MATCHED
     WITH AFFIRMS STATION WEATHER DATA.  INCLUDE DECIMAL POINT.
>3.
12. 1.1.  DISTRICT NAME.
          ENTER FROM 1 TO 20 CHARACTERS.
>TROY (D4)
12. 1.2.  DISTRICT ADP CODE.
          ENTER ADP CODE (AND DECIMAL POINT) AS USED ON 5100-29 REPORTS.
>4.
12. 1.3.  DISTRICT AFFIRMS STATION.
          ENTER SEQUENTIAL NUMBER (FROM COLUMN 1) OF AFFIRMS STATION
          REPRESENTING TROY (D4)             DISTRICT.
          ASSIGN ONE OF THE FOLLOWING STATIONS (1.- 2.):
           1.   240112  TROY RD AFFIRMS
           2.   240116  BIG SWEDE MTN.

>1.
12. 2.1.  DISTRICT NAME.
          ENTER FROM 1 TO 20 CHARACTERS.
>LIBBY (D5)
12. 2.2.  DISTRICT ADP CODE.
          ENTER ADP CODE (AND DECIMAL POINT) AS USED ON 5100-29 REPORTS.
>5.
12. 2.3.  DISTRICT AFFIRMS STATION.
          ENTER SEQUENTIAL NUMBER (FROM COLUMN 1) OF AFFIRMS STATION
          REPRESENTING LIBBY (D5)            DISTRICT.
          ASSIGN ONE OF THE FOLLOWING STATIONS (1.- 2.):
           1.   240112  TROY RD AFFIRMS
           2.   240116  BIG SWEDE MTN.

>2.
12. 3.1.  DISTRICT NAME.
          ENTER FROM 1 TO 20 CHARACTERS.
>CABINET (D7)
12. 3.2.  DISTRICT ADP CODE.
          ENTER ADP CODE (AND DECIMAL POINT) AS USED ON 5100-29 REPORTS.
>7.
12. 3.3.  DISTRICT AFFIRMS STATION.
          ENTER SEQUENTIAL NUMBER (FROM COLUMN 1) OF AFFIRMS STATION
          REPRESENTING CABINET (D7)          DISTRICT.
          ASSIGN ONE OF THE FOLLOWING STATIONS (1.- 2.):
           1.   240112  TROY RD AFFIRMS
           2.   240116  BIG SWEDE MTN.

>2.
13.  FIRE REPORT FILE LISTING.
     ENTER "YES" IF YOU WANT A FIRE REPORT FILE LISTING.
>YES


14.  WEATHER DATA FILE LISTING.
     ENTER "YES" IF YOU WANT A WEATHER FILE LISTING.
>YES




ENTER "YES" IF YOU WANT A SAMPLE CSSG*R1LIB.RXBUILD2 RUN STREAM.
>YES

*************************************************************
   PROCEDURE TO BUILD FIRE REPORT AND WEATHER DATA FILES
*************************************************************

TO CREATE THE FIRE REPORT AND WEATHER DATA FILES, YOU MUST
ASSIGN AND USE THE FOLLOWING FILES:

1. @ASG,A  THE RXBUILD DIRECTIVE FILE YOU JUST CREATED BY THIS
           PROGRAM.
2. @ASG,A  A FILE CONTAINING FIRE REPORTS GENERATED BY THE NATL.
           FIRE OCCURRENCE LIBRARY NFODL*PROGRAMS.RETRIEVE PROGRAM.
3. @ASG,CP A FILE TO CONTAIN THE NEWLY GENERATED FIRE REPORT FILE.
4. @ASG,CP A FILE TO CONTAIN THE NEWLY GENERATED WEATHER DATA
           FILE.



HIT CARRIAGE RETURN TO CONTINUE.

>
```

Exhibit 2—(con.)



```
THE FOLLOWING PROCEDURE SHOULD BE USED  (USE YOUR OWN QUALIFIER
AND FILENAMES TO REPLACE THOSE IN PARENTHESIS BELOW):

1.  @RUN,...
2.  @ASG,A    (INPUT DIRECTIVE FILE YOU JUST CREATED)
3.  @ASG,A    (NFODL FIRE REPORT FILE)
4.  @USE  10.,(NFODL FIRE REPORT FILE)
5.  @DELETE,C (FILE TO CONTAIN FIRE REPORT OUTPUT)
6.  @ASG,CP   (FILE TO CONTAIN FIRE REPORT OUTPUT)
7.  @USE   3.,(FILE TO CONTAIN FIRE REPORT OUTPUT)
8.  @DELETE,C (FILE TO CONTAIN WEATHER DATA OUTPUT)
9.  @ASG,CP   (FILE TO CONTAIN WEATHER DATA OUTPUT),F40///800.
10. @USE   8.,(FILE TO CONTAIN WEATHER DATA OUTPUT)
11. @ADD,P    (INPUT DIRECTIVE FILE YOU JUST CREATED)
12. @FIN


END CSSG*R1LIB.RXBUILD             DATE: 062283      TIME: 110450
>@FIN



  RUNID: S22CDB   ACCT: 1122314412     PROJECT: SEMLIB

***** DISPLAYED LOG ENTRY SECTION *****
  11:05:19        S22CDB FIN

***** RESOURCE UTILIZATION SECTION *****
    RESOURCE                                                AVG
      TIME          CPU           IO            CCER       SIZE
  ------------ ------------ ------------ ------------ ----
  00:00:01.979 00:00:00.364 00:00:01.459 00:00:07.470   6K  SUMMARY

  IMAGES  READ:   82          PAGES:  8

  START:    10:53:28 JUN 22,1983    FIN:  11:05:19 JUN 22,1983

***** COST SECTION *****

  CHARGES BASED ON    DEMAND RUN
  RT  ($001.35/MIN)    :$000000.04
  CPU ($002.88/MIN)    :$000000.01
  IO  ($001.50/MIN)    :$000000.03
  CCER($002.88/MIN)    :$000000.35
                        ----------

  CONNECT TIME CHARGE: $000001.19

  ESTIMATED TOTAL COST:$000001.62
                        ==========
*TERMINAL INACTIVE*
>
```

Exhibit 2—(con.)

Date 3-82

RXBUILD INPUT WORKSHEET

SHEET NO. 1 -- RUN IDENTIFICATION

1. TITLE. (Enter 1 to 80 characters.)

CABINET WILDERNESS FIRE MANAGEMENT PLAN

2. USER NAME. (Enter 1 to 80 characters.)

COLLIN D. BEVINS

3. REGION NAME OR NUMBER. (Enter 1 to 80 characters.)

NORTHERN REGION

4. FOREST NAME. (Enter 1 to 80 characters.)

KOOTENAI

5. FOREST ADP CODE. 14.

6. NUMBER OF AFFIRMS WEATHER STATIONS TO BE USED IN THIS RUN.[1] 2.

List of AFFIRMS stations to be used. List in order of increasing station number - smallest number first, largest number last.

6.1. TROY 240112

6.2. BIG SWEDE

6.__.

6.__.

6.__.

6.__.

---

[1] Complete a separate Sheet No. 2 for each of the AFFIRMS stations listed in Item No. 6 above.

Page 1 of 7

Exhibit 3a.—Sample RXBUILD Input Worksheet No. 1, Run Identification.

Date 3-82 RXBUILD INPUT WORKSHEET

SHEET NO. 2 -- AFFIRMS STATION PARAMETERS

6.1. 6-DIGIT AFFIRMS STATION ID. 240112.

6.1.1 AFFIRMS STATION NAME.[1] TROY RD AFFIRMS

6.1.2 AFFIRMS STATION ELEVATION. 1950.

6.1.3 AFFIRMS STATION LATITUDE. 48.

6.1.4 NFDRS FUEL MODEL. G

6.1.5 NFDRS SLOPE CLASS. 3.

6.1.6 NFDRS HERBACEOUS TYPE. P

6.1.7 NFDRS CLIMATE CLASS. 3.

6.1.8 NFDRS GREENUP DATE. 601.

6.1.9 NFDRS FIRST FREEZE DATE. 915.

6.1.10 NFDRS WEEKDAY MAN RISK FACTOR. 1.

6.1.11 NFDRS WEEKEND MAN RISK FACTOR. 1.

6.1.12 NFDRS LIGHTNING SCALING FACTOR. 1.

6.1.13 NUMBER OF MANNING VARIABLES.[2] 2.

---

[1] 20 characters maximum.

[2] Complete Sheet No. 3 if Item No. 6.__.13 is greater than 0. A separate Sheet No. 3 must be completed for each AFFIRMS station indicated in Item 6, Sheet No. 1.

Page 2 of 7

Exhibit 3b.—Sample RXBUILD Input Worksheet No. 2, AFFIRMS Station Parameters, for first AFFIRMS station to be used in this run (AFFIRMS station with smallest ID number).

Date 3-82

RXBUILD INPUT WORKSHEET

SHEET NO. 3 -- RUN IDENTIFICATION

AFFIRMS STATION NO. 240112

MANNING VARIABLE NO. 1

6.1.13.1.1	BASE VARIABLE FOR MANNING LEVEL.	53.
6.1.13.1.2	NO. OF MANNING LEVEL CLASSES.	5.
6.1.13.1.3	90th PERCENTILE VALUE OF BASE VARIABLE.	62.
6.1.13.1.4	97th PERCENTILE VALUE OF BASE VARIABLE.	69.

MANNING VARIABLE NO. 2

6.1.13.2.1	BASE VARIABLE FOR MANNING LEVEL.	56.
6.1.13.2.2	NO. OF MANNING LEVEL CLASSES.	5.
6.1.13.2.3	90th PERCENTILE VALUE OF BASE VARIABLE.	59.
6.1.13.2.4	97th PERCENTILE VALUE OF BASE VARIABLE.	68.

MANNING VARIABLE NO. 3

6.__.13.3.1	BASE VARIABLE FOR MANNING LEVEL.	__ __ __
6.__.13.3.2	NO. OF MANNING LEVEL CLASSES.	__ __ __
6.__.13.3.3	90th PERCENTILE VALUE OF BASE VARIABLE.	__ __ __ __
6.__.13.3.4	97th PERCENTILE VALUE OF BASE VARIABLE.	__ __ __ __

Page 3 of 7

Exhibit 3c.—Sample RXBUILD Input Worksheet No. 3, Manning Variable Parameters, for first AFFIRMS station to be used in this run (AFFIRMS station with smallest ID number).

Date 3-82

RXBUILD INPUT WORKSHEET

SHEET NO. 2 -- AFFIRMS STATION PARAMETERS

6.2.	6-DIGIT AFFIRMS STATION ID.	240116.
6.2.1	AFFIRMS STATION NAME.[1]	BIG SWEDE MTN
6.2.2	AFFIRMS STATION ELEVATION.	_4336.
6.2.3	AFFIRMS STATION LATITUDE.	48.
6.2.4	NFDRS FUEL MODEL.	G
6.2.5	NFDRS SLOPE CLASS.	3.
6.2.6	NFDRS HERBACEOUS TYPE.	P
6.2.7	NFDRS CLIMATE CLASS.	3.
6.2.8	NFDRS GREENUP DATE.	_601.
6.2.9	NFDRS FIRST FREEZE DATE.	_915.
6.2.10	NFDRS WEEKDAY MAN RISK FACTOR.	__1.
6.2.11	NFDRS WEEKEND MAN RISK FACTOR.	__1.
6.2.12	NFDRS LIGHTNING SCALING FACTOR.	__1.
6.2.13	NUMBER OF MANNING VARIABLES.[2]	2.

---

[1] 20 characters maximum.

[2] Complete Sheet No. 3 if Item No. 6.__.13 is greater than 0. A separate Sheet No. 3 must be completed for each AFFIRMS station indicated in Item 6, Sheet No. 1.

Page 4 of 7

Exhibit 3d.—Sample RXBUILD Input Worksheet No. 2, AFFIRMS Station Parameters, for second AFFIRMS station to be used in this run (AFFIRMS station with largest ID number).

Date 3-82

RXBUILD INPUT WORKSHEET

SHEET NO. 3 -- RUN IDENTIFICATION

AFFIRMS STATION NO. 2 4 0 1 1 6

MANNING VARIABLE NO. 1

6.2.13.1.1	BASE VARIABLE FOR MANNING LEVEL.	53.
6.2.13.1.2	NO. OF MANNING LEVEL CLASSES.	5.
6.2.13.1.3	90th PERCENTILE VALUE OF BASE VARIABLE.	62.
6.2.13.1.4	97th PERCENTILE VALUE OF BASE VARIABLE.	69.

MANNING VARIABLE NO. 2

6.2.13.2.1	BASE VARIABLE FOR MANNING LEVEL.	56.
6.2.13.2.2	NO. OF MANNING LEVEL CLASSES.	5.
6.2.13.2.3	90th PERCENTILE VALUE OF BASE VARIABLE.	59.
6.2.13.2.4	97th PERCENTILE VALUE OF BASE VARIABLE.	68.

MANNING VARIABLE NO. 3

6.__.13.3.1	BASE VARIABLE FOR MANNING LEVEL.	___ ___ ___
6.__.13.3.2	NO. OF MANNING LEVEL CLASSES.	___ ___ ___
6.__.13.3.3	90th PERCENTILE VALUE OF BASE VARIABLE.	___ ___ ___ ___
6.__.13.3.4	97th PERCENTILE VALUE OF BASE VARIABLE.	___ ___ ___ ___

Page 5 of 7

Exhibit 3e.—Sample RXBUILD Input Worksheet No. 3, Manning Variable Parameters, for second AFFIRMS station to be used in this run (AFFIRMS station with largest ID number).

Date 3-82

SHEET NO. 4 -- DATE PARAMETERS

7. BEGINNING YEAR. 70.

8. ENDING YEAR. 80.

9. BEGINNING SEASON DATE. 101.

10. ENDING SEASON DATE. 1231.

11. NFWDL FILE NAME. 21-24.

12. NUMBER OF DISTRICTS.[1] 3.

13. FIRE REPORT LISTING? YES

14. WEATHER DATA FILE LISTING? YES

---

[1] Information on each District indicated here included on a Sheet No. 5, District Parameters.

Page 6 of 7

Exhibit 3f.—Sample RXBUILD Input Worksheet No. 4, Date Parameters.

Date 3-82

RXBUILD INPUT WORKSHEET

SHEET NO. 5 -- DISTRICT PARAMETERS

DISTRICT NO. 1

12.1.1 DISTRICT NAME. TROY D4

12.1.2 DISTRICT ADP CODE. 4.

12.1.3 DISTRICT AFFIRMS STATION. (TROY-240112) 1.

DISTRICT NO. 2

12.2.1 DISTRICT NAME. LIBBY D5

12.2.2 DISTRICT ADP CODE. 5.

12.2.3 DISTRICT AFFIRMS STATION. (BIG SWEDE-240116) 2.

DISTRICT NO. 3

12.3.1 DISTRICT NAME. CABINET D7

12.3.2 DISTRICT ADP CODE. 7.

12.3.3 DISTRICT AFFIRMS STATION. (BIG SWEDE-240116) 2.

Page 7 of 7

Exhibit 3g.—Sample RXBUILD Input Worksheet No. 5, District Parameters. Sheet No. 5 must contain information about each Ranger District indicated in item 12, sheet No. 4.

RXBUILD Batch Processing

Program CSSG*R1LIB.RXBUILD creates a directive file (qual*rxbuild-dir.) that must be @ADD'ed to initiate batch processing of CSSG*R1LIB.RXBUILD2 from a DEMAND terminal (step 5, table 1, and fig. 1). Data files assigned to the run include the NFODL fire report file (NFOrrffSPSS*mmddyyhhmmss.), an output file to contain the processed fire report data (qual*firefile.), and an 800-track output file to contain the processed AFFIRMS fire-weather data (qual*weatherfile.).

The following run stream is used to initiate RXBUILD batch processing from a DEMAND terminal:

```
Image  0         1         2         3         4
 No.   1234567890123456789012345678901234567890
  1    @RUN
  2    @ASG,A    NFOrrffSPSS*mmddyyhhmmss
  3    @USE 10,,NFOrrffSPSS*mmddyyhhmmss
  4    @ASG,CP   qual*firefile
  5    @USE  3,,qual*firefile.
  6    @ASG,CP   qual*weatherfile.,F40///800
  7    @USE  8   qual*weatherfile.
  8    @ASG,A    qual*rxbuild-dir.
  9    @ADD,P    qual*rxbuild-dir
 10    @FIN
```

It is not necessary to @ASG the Region 1 shared library or @XQT the executable element RXBUILD2 because these steps are performed dynamically from the RXBUILD directive file (qual*rxbuild-dir.).

The two mass storage output files "qual*firefile." and "qual*weatherfile." are available for 6 calendar days following their creation by the above run stream unless @SAVE'd for a longer period. It is generally less expensive to re-create both data files as needed rather than @SAVE more than 800 tracks of mass storage.

RXBUILD Costs

DEMAND terminal data entry using program RXBUILD takes less than 20 minutes for the example in exhibit 2. Total time would be less if no introductory, update, or initiation information were requested. DEMAND costs for the example were $0.46, and connect time charges $1.48, for a total cost of less than $2.

Executable element RXBUILD2 batch processing of the directive file created in exhibit 2 cost $4.72 at P priority. The cost includes FIREDATALIB*PROGRAMS.GETDATA2 processing to retrieve fire-weather observations from the NFWDL and NFDR78*FIREFAMILY.FIREDAT1 processing to derive NFDRS indices. Both routines are dynamically assigned and initiated during RXBUILD batch processing.

PROGRAM RXFIRES

RXFIRES Initiation

Use program CSSG*R1LIB.RXFIRES to enter items from the RXFIRES input worksheets to a DEMAND terminal. A file (qual*rxfires-dir.) must be assigned to logical unit 7 to hold the directives written by RXFIRES. The following run stream is used to initiate CSSG*R1LIB.RXFIRES interactive processing at a DEMAND terminal (step 8, table 1, and fig. 1).

```
Image  0         1         2         3         4
 No.   1234567890123456789012345678901234567890
  1    @RUN,..
  2    @ASG,A    CSSG*R1LIB.
  3    @ASG,UP qual*rxfires-dir.
  4    @USE 7 ,qual*rxfires-dir.
  5    @XQT     CSSG*R1LIB.RXFIRES
```

All items entered from the RXFIRES worksheet into the terminal are edited and written onto the RXFIRES directive file named "qual*rxfires-dir.".

RXFIRES Data Entry

RXFIRES first asks the terminal operator whether an introduction is to be printed. The introduction contains one screen (24 lines) of program description, one screen of input rules, one screen of RXFIRES interactive initiation procedures, one screen of file assignment information, and one screen of RXFIRES batch processing initiation information. All these topics are discussed in the following pages.

RXFIRES then prompts the terminal operator for all items from the RXFIRES input worksheet. The following rules apply:

1. All numeric entries must contain a decimal point. Failure to include the decimal will cause an error diagnostic to be printed to the terminal. The operator then has another chance to correctly reenter the data.
2. Numeric entries may be either right- or left-justified within the entry field provided.
3. Program execution may be terminated at any time by entering "STOP" beginning in the left-most column (it may be necessary to enter "STOP" twice successively). The program will terminate without creating a directive file on logical unit 7.

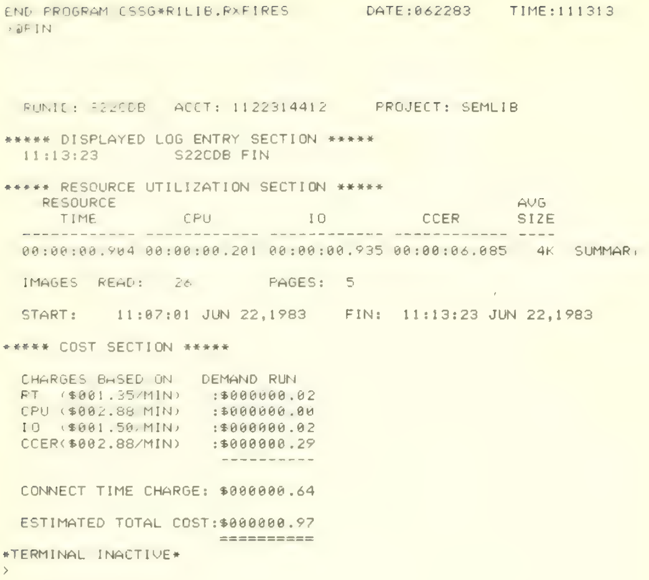
All entries are checked for value-range and decimal point. Self-explanatory error diagnostics are printed to the terminal if data entries are out of range or do not have a decimal point. The operator will be given another chance to correctly reenter the data or "STOP".

A sample RXFIRES input session is shown in exhibit 4 for the Cabinet Wilderness Area fire management plan. The data were entered from the sample RXFIRES input worksheets shown in exhibit 5.

```
@ASG,A  CSSG*R1LIB.
FACILITY WARNING  000200000000
>@ASG,CP QUALIFIER*RXFIRES-DIR.
READY
>@USE 7.,QUALIFIER*RXFIRES-DIR.
READY
>@XQT     CSSG*R1LIB.RXFIRES



BEGIN CSSG*R1LIB.RXFIRES



ENTER "YES" IF YOU WANT TO SEE INTRODUCTION.
>YES


PROGRAM         CSSG*R1LIB.RXFIRES

LANGUAGE        ASCII 3.9X-77 FORTRAN

MACHINE         UNIVAC 1100/84

USAGE           INTERACTIVE DEMAND (80 CHARACTERS)

PROGRAMMED      COLLIN D. BEVINS
                SYSTEMS FOR ENVIRONMENTAL MANAGEMENT
                P.O. BOX 3776
                MISSOULA, MONTANA  59806
                (406) 549-7478

REFERENCE       BEVINS,C.D., AND W.C. FISCHER.  1982.
                A COMPUTER SYSTEM FOR TESTING FIRE MANAGEMENT
                PRESCRIPTIONS, PART II: TERMINAL OPERATORS' MANUAL.
                USDA FOREST SERVICE GEN. TECH. REP. INT-    .
                INTERMTN. FOREST & RANGE EXPT. STN., OGDEN, UT. 84401

HIT CARRIAGE RETURN TO CONTINUE.
>

                         *************
                            ESCAPE'
                         *************

IF YOU WISH TO TERMINATE THIS PROGRAM AT ANY TIME,
ENTER THE COMMAND 'STOP' FOLLOWED BY A CARRIAGE RETURN.


                       *****************
                          INPUT RULES
                       *****************

1.  ALL INFORMATION MUST BE ENTERED BEGINNING IN COLUMN 1 .

2.  ALL NUMERIC DATA MUST INCLUDE A DECIMAL POINT .
    (TO BE SAFE, TERMINATE ALL INPUT WITH A DECIMAL POINT.)



HIT CARRIAGE RETURN TO CONTINUE.
>
                    **************************
                       CATALOG YOUR OUTPUT'
                    **************************

CSSG*R1LIB.RXFIRES IS AN INTERACTIVE PROGRAM THAT ASKS YOU
FOR INFORMATION REQUIRED TO BUILD A DIRECTIVE FILE TO @ADD
TO TEST ALTERNATIVE UNSCHEDULED FIRE PRESCRIPTIONS.

THE PROGRAM READS EACH PIECE OF INFORMATION ENTERED, CHECKS IT
FOR OBVIOUS ERRORS, AND WRITES IT TO AN OUTPUT FILE ON UNIT 7
FOR YOUR LATER USE.  YOU MUST HAVE @ASG'D AND @USE'D A FILE TO HOLD
THE PROGRAM OUTPUT ON LU 7 OR IT WILL DISAPPEAR AT @FIN TIME.

THE FOLLOWING RUN STREAM SHOULD BE USED:

1. @RUN,...
2. @ASG,A CSSG*R1LIB.
3. @ASG,CP (YOUR QUALIFIER*FILENAME)
4. @USE 7.,(YOUR QUALIFIER*FILENAME).
5. @XQT CSSG*R1LIB.RXFIRES

IF YOU DID NOT FOLLOW THE ABOVE PROCEDURE, ENTER 'STOP'
AND TRY AGAIN.  ENTER CARRIAGE RETURN TO CONTINUE.


*************************************************************
   PROCEDURE TO ACCESS AND RUN PROGRAM RXFIRES2
*************************************************************

TO SUBMIT THE NEWLY CREATED RXFIRES DIRECTIVE FILE,
YOU MUST ASSIGN AND USE THE FOLLOWING FILES:

1. @ASG,A THE RXFIRES DIRECTIVE FILE YOU JUST CREATED BY THIS
          PROGRAM.
2. @ASG,A FIRE REPORT FILE CREATED BY RXBUILD AND RXBUILD2.
3. @ASG,A FIRE WEATHER FILE CREATED BY RXBUILD AND RXBUILD2.
```

```
HIT CARRIAGE RETURN TO CONTINUE.
>


THE FOLLOWING PROCEDURE SHOULD BE USED  (USE YOUR OWN QUALIFIER
AND FILENAMES TO REPLACE THOSE IN PARENTHESIS BELOW):

1.   @RUN,...
2.   @ASG,A  (RXFIRES DIRECTIVE FILE YOU JUST CREATED)
3.   @ASG,A  (FIRE REPORT FILE CREATED BY RXBUILD)
4.   @USE 3.,(FIRE REPORT FILE CREATED BY RXBUILD)
5.   @ASG,A  (FIRE WEATHER FILE CREATED BY RXBUILD)
6.   @USE 8.,(FIRE WEATHER FILE CREATED BY RXBUILD)
7.   @ADD,P  (RXFIRES DIRECTIVE FILE YOU JUST CREATED)
8.   @FIN






1. RUN NAME.
    ENTER FROM 1 TO 80 CHARACTERS.
>CABINET WILDERNESS AREA FIRE MANAGEMENT PLAN: RUN NO. 1
2. USER NAME.
    ENTER FROM 1 TO 80 CHARACTERS.
>JOSEPH M. GLASSY
3. EXCLUSION CRITERIA.
    ENTER A VARIABLE CODE FROM 1. TO 60. UNDER THE COLUMN  HEADED "NO.".

    ENTER AN ARGUMENT UNDER COLUMN HEADED "AR".
    THE ARGUMENTS ARE ---EQ,NE,GT,LT,GE,LE---.

    ENTER VALUE OF 1 TO 10 DIGITS UNDER THE
    COLUMN HEADING "1234567890".
    HIT CARRIAGE RETURN TWICE TO CONTINUE TO NEXT STEP.


    YOU MAY ENTER FROM 0. TO 99. EXCLUSION CRITERIA.
    ...INCLUDE THE DECIMAL POINT...

 NO. AR 1234567890.
 --- -- -----------
>26. LT 4.
> 4. LT 4.
  4. GT 7.
> 4. EQ 6.

4.  SUPPRESSION CRITERIA.
    ENTER A VARIABLE CODE FROM 1. TO 60. UNDER THE COLUMN  HEADED "NO.".

    ENTER AN ARGUMENT UNDER COLUMN HEADED "AR".
    THE ARGUMENTS ARE ---EQ,NE,GT,LT,GE,LE---.

    ENTER VALUE OF 1 TO 10 DIGITS UNDER THE
    COLUMN HEADING "1234567890".

    ENTER NUMBER OF DAYS PRIOR TO FIRE START THAT SUPPRESSION
    CRITERIA IS ENFORCED UNDER COLUMNS HEADED "DAYS".

    YOU MAY ENTER FROM 0. TO 99. SUPPRESSION CRITERIA.
    HIT CARRIAGE RETURN TWICE TO CONTINUE TO NEXT STEP.

    ...INCLUDE THE DECIMAL POINT...

 NO. AR 1234567890. DAYS.
 --- -- ----------- -----
>15. NE 1.
>53. GT 47.              4.
>
5. OUTPUT LEVEL.
    ENTER 1., 2., OR 3.
>3.
5.1  INCHES OF PRECIPITATION.
    ENTER INCHES OF RAIN REQUIRED TO EXTINGUISH FIRE.
    ...INCLUDE THE DECIMAL POINT...

>0.45
5.2  FIRE CASE HISTORY VARIABLES.
    ENTER FROM 0. TO 12. VARIABLE CODES TO BE PRINTED
    IN THE INDIVIDUAL MANAGEMENT FIRE CASE HISTORIES.

    ENTER UNDER COLUMNS HEADED "01." TO "12.".

    ...INCLUDE THE DECIMAL POINT...

 01. 02. 03. 04. 05. 06. 07. 08. 09. 10. 11. 12.
 --- --- --- --- --- --- --- --- --- --- --- ---
>08. 09. 14. 19. 22. 23. 51. 52. 53. 56.


5.3  FIRE LOAD SUMMARY TABLE DATES
    ENTER DATES TO BE USED IN FIRE LOAD SUMMARY TABLE.
    ENTER DATES AND YEARS UNDER APPROPRIATE COLUMNS
    ...INCLUDE THE DECIMAL POINT...

 FIRST LAST  FIRST LAST.
 MMDD. MMDD. YEAR. YEAR.
 ----- ----- ----- -----
>0601. 0920. 1970. 1980.
```

Exhibit 4.—Sample Program RXFIRES Data Entry Session.



```
END PROGRAM CSSG*R1LIB.RXFIRES        DATE:062283    TIME:111313
>@FIN



  RUNID: S22CDB   ACCT: 1122314412      PROJECT: SEMLIB

***** DISPLAYED LOG ENTRY SECTION *****
  11:13:23         S22CDB FIN

***** RESOURCE UTILIZATION SECTION *****
    RESOURCE                                                 AVG
      TIME           CPU            IO            CCER      SIZE
  ------------ ------------ ------------ ------------ ----
  00:00:00.904 00:00:00.201 00:00:00.935 00:00:06.085   4K  SUMMAR

  IMAGES  READ:   26          PAGES:  5

  START:    11:07:01 JUN 22,1983    FIN:  11:13:23 JUN 22,1983

***** COST SECTION *****

  CHARGES BASED ON   DEMAND RUN
  RT  ($001.35/MIN)    :$000000.02
  CPU ($002.88 MIN)    :$000000.00
  IO  ($001.50/MIN)    :$000000.02
  CCER($002.88/MIN)    :$000000.29
                        ----------

  CONNECT TIME CHARGE: $000000.64

  ESTIMATED TOTAL COST:$000000.97
                       ==========
*TERMINAL INACTIVE*
>
```

Exhibit 4.—(con.)

Date 3-82

RXFIRES INPUT WORKSHEET

SHEET NO. 1 -- RUN IDENTIFICATION

1. RUN NAME.

CABINET WILDERNESS FIRE MANAGEMENT PLAN

2. USER NAME.

COLLIN BEVINS

3. EXCLUSION CRITERIA. (Use Sheet No. 2)

4. FIRE SUPPRESSION CRITERIA. (Use Sheet No. 3)

5. OUTPUT LEVEL. 3.

5.1 INCHES OF PRECIPITATION. 0.45

5.2 FIRE CASE HISTORY VARIABLES.

0 1.	0 2.	0 3.	0 4.	0 5.	0 6.	0 7.	0 8.	0 9.	1 0.	1 1.	1 2.
8.	9.	14.	19.	22.	23.	51.	52.	53.	56.		

5.3 FIRE LOAD SUMMARY TABLE DATES.

First MMDD.	Last MMDD.	First YEAR.	Last YEAR.
0601.	0920.	1970.	1980.

Page 1 of 3

Exhibit 5a.—Sample RXFIRES Input Worksheet No. 1, Run Identification.

Date 3-82

RXFIRES INPUT WORKSHEET

SHEET NO. 2 -- FIRE EXCLUSION CRITERIA

EXCLUDE FIRES IF:

3.1 VARIABLE CODE	3.2 ARITHMETIC ARGUMENT	3.3 VALUE CODE	3.4 VARIABLE NAME	3.5 VARIABLE MEASURE
26.	LT	4.	ELEVATION	4500 FT.
4.	LT	4.		
4.	GT	7.	DISTRICT *	
4.	EQ	6.		

* EXCLUDE ALL DISTRICTS EXCEPT:

TROY (4)
LIBBY (5)
CABINET (7)

Page 2 of 3

Exhibit 5b.—Sample RXFIRES Input Worksheet No. 2, Fire Exclusion Criteria.

Date 3-82

RXFIRES INPUT WORKSHEET

SHEET NO. 3 -- FIRE SUPPRESSION CRITERIA

SUPPRESS FIRES IF:

4.1 VARIABLE CODE	4.2 ARITHMETIC ARGUMENT	4.3 VALUE CODE	4.4 PREVIEW DAYS	4.5 VARIABLE NAME	4.6 VARIABLE MEASURE
15.	NE	1.		CAUSE	LIGHTNING
53.	GT	47.	4.	ERC	80 PERCENTILE
		.			
		.			
		.			
		.			
		.			
		.			
		.			
		.			
		.			
		.			
		.			
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		.			
		.			
		.			
		.			
		.			
		.			

Page 3 of 3

Exhibit 5c.—Sample RXFIRES Input Worksheet No. 3, Fire Suppression Criteria.

RXFIRES Batch Processing

Program CSSG*R1LIB.RXBUILD creates a directive file (qual*rxfires-dir.) that must be @ADD'ed to initiate batch processing of CSSG*R1LIB.RXFIRES2 from a DEMAND terminal (step 9, table 1, and fig. 1). Data files assigned to the run include the fire report file (qual*firefile.) and fire-weather file (qual*weatherfile.) created by a previous RXBUILD run.

The following run stream is used to initiate RXFIRES batch processing from a DEMAND terminal:

```
Image  0         1         2         3         4
 No.   1234567890123456789012345678901234567890
  1    @RUN.
  2    @ASG A  qual*firefile.
  3    @USE 3.,qual*firefile.
  4    @ASG.A  qual*weatherfile
  5    @USE 8.,qual*weatherfile.
  6    @ASG A  qual*rxfires-dir
  7    @ADD P  qual*rxfires-dir.
  8    @FIN
```

It is not necessary to @ASG the Region 1 shared library or @XQT the executable element RXFIRES2 because these steps are performed dynamically from the RXFIRES directive file (qual*rxfires-dir.).

Programs RXBUILD and RXFIRES may be submitted for batch processing in tandem, using the following run stream:

```
Image  0         1         2         3         4
 No.   1234567890123456789012345678901234567890
  1    @RUN
  2    @ASG,A   NFOrrffSPSS*mmddyyhhmmss
  3    @USE 10 .NFOrrffSPSS*mmddyyhhmmss
  4    @ASG,CP  qual*firefile
  5    @USE  3 .qual*firefile.
  6    @ASG,CP  qual*weatherfile.,F40///800
  7    @USE  8 .qual*weatherfile.
  8    @ASG,A   qual*rxbuild-dir
  9    @ADD,P   qual*rxbuild-dir
 10    @ASG,A   qual*rxfires-dir
 11    @ADD,P   qual*rxfires-dir.
 12    @FIN
```

RXFIRES Costs

DEMAND terminal data entry using program RXFIRES takes about 20 minutes for the example in exhibit 4. Total time would be less if no introductory information was requested. DEMAND costs for the example were $0.38, and connect time charges $0.89, for a total cost of less than $2.

Batch processing of the executable element RXFIRES2 directive file (exhibit 5) cost $2.64 at P priority.

PUBLICATIONS CITED

Bevins, Collin D.; Fischer, William C. A computer system for testing fire management prescriptions: part 1—user's manual. Gen. Tech. Rep. INT-155. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1983. 42 p.

Deeming, John E.; Burgan, Robert E.; Cohen, Jack D. The National Fire-Danger Rating System—1978. Gen. Tech. Rep. INT-39. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1977. 63 p.

Furman, R. William; Brink, Glen E. The National Fire Weather Library: what it is and how to use it. Gen. Tech. Rep. RM-19. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station; 1975. 8 p.

Yancik, Richard F.; Roussopoulos, Peter J. User's guide to the National Fire Occurrence Data Library. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station; 1982. 25 p.

Bevins, Collin D.; Fischer, William C. A computer system for testing fire management prescriptions: part 2—computer terminal operator's manual. Gen. Tech. Rep. INT-156. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1983. 22 p.

Describes structure of a computer system that allows fire managers to evaluate alternative prescriptions for unscheduled prescribed fires. Provides instructions for initial data entry and execution of programs RXBUILD and RXFIRES, the two main components of the system. A companion publication, Part 1—User's Guide (Bevins and Fischer 1983), is available as a separate general technical report.

KEYWORDS: prescribed fire, fire management, fire management planning, land management planning, computer systems

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